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NEAR REAL TIME VHF TELEMETRY OF NEAR SHORE OCEANOGRAPHIC DATA

by

Douglas L. McKinney

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Thesis Advisor Steven R. Ramp

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The equipment used in VHF NBFM packet is light weight, has low power consumption and is inexpensive when used ith commercially available amateur radio equipment. Tests of a prototype system suggest that a VHF NBFM packet system a practical tool for near shore buoy telemetry of in situ oceanographic data.

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Near Real Time VHF Telemetry of Near Shore Oceanographic Data

by

Douglas L. McKinney
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B.A., San Francisco State University, 1969

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ABSTRACT

This thesis reports on the development and tests of a low cost automated telemetry system. This system daily transmits the last 24 hours of collected data from a near shore moored buoy system.

Investigation into the different telemetry modes resulted in selecting a very high frequency (VHF) narrow band frequency modulation (NBFM) packet networking system. The telemetry system features line-of-sight propagation, resistance to radio interference and includes a digital error checking routine.

The equipment used in VHF NBFM packet is light weight, has low power consumption and is inexpensive when used with commercially available amateur radio equipment. Tests of a prototype system suggest that a VHF NBFM packet system is a practical tool for near shore buoy telemetry of in situ oceanographic data.

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I. INTRODUCTION

A. BACKGROUND

1. Purpose of data collection for the study of ocean currents.

Our understanding of the three dimensional ocean circulation in physical oceanography results from the accumulation of data over the last hundred years. Improvements in data collection techniques have expanded our ability to scientifically explain the dynamics of large scale distributions of the physical characteristics of the ocean throughout the water column. Smaller scale studies at ocean boundaries, along the coasts in regions of upwelling and downwelling, are answering questions about the relationships between wind driven surface currents and thermohaline circulations of deep currents, and influences of turbulent motions. Oceanographers have come to realize that the ocean is populated by small and medium scale (mesoscale) circulation features (eddies), which influence the mixing and transport of water masses and aid in the formation of new water masses. Near real time data acquisition is a new research area and is essential to support ocean circulation prediction.

The study of ocean currents is developed from oceanographic measurements and dynamical oceanographic theories. Measurements used to determine ocean currents are taken directly and indirectly. Direct measurements are obtained by using recording current meters in the region of interest to record the velocity fields. The primary method of indirect measurement uses routine observations of the distribution of water properties at various depths over a fixed area. The most popular method of observation is to use a conductivity, temperature and depth (CTD) instrument. The CTD is lowered over the side of a ship and sends the CTD data from various depths, back to the ship through the winch cable. Salinity and density are computed from the CTD data from which inferences are made on the steady or the slowly varying components of the velocity fields based on the geostrophic relations.

The objective of this thesis is to augment direct measurement technology by providing a near real time telemetry system for the deployed current meter. Near real time telemetry removes the uncertainty of the performance of long term moored systems and provides the opportunity to use moored current data to help plan field programs. Moored buoy systems currently require recovery after a fixed (up to 24 months) deployment period. Obtaining the data from a moored buoy system requires recovery to

read the current meter recorders. Using a telemetry approach for near shore buoy data recovery has several notable advantages:

- Data collection can be in near real time (last 24 hours) for input to prediction or forecasting models.
- High resolution satellite (SST, SSM/I and AVHRR) data can be collected in real time to coordinate near real time investigations of current variabilities, which were detected through the use of near real time telemetry from a near shore buoy.
- Expendable moorings can be considered.
- System operation at the mooring site can be verified daily to indicate any system changes resulting from hostile environmental impacts such as those caused by shipping, fishermen and the seas.

Recovery of oceanographic data for use in near real time projects is an important and ongoing effort. Various oceanographic institutions and federal agencies are involved in developing real time data collection systems:

- The University Research Initiative Program (URIP) is a five year Office of Naval Research (ONR) funded program involving Woods Hole Oceanographic Institution (WHOI), Massachusetts Institute of Technology (MIT) and Harvard. The objectives are to advance the state of the art in ocean data collection using telemetry, satellite remote sensing and numerical ocean modeling. Under telemetry the aim is reliable transfer of data from in situ oceanographic instruments to laboratory computers [Frye, 1987]. Figure 1 shows some of the technical approaches being investigated at WHOI.
- Texas A&M University has an ongoing program to develop the ability to communicate remotely with moored or drifting instruments using transhorizon VHF telemetry [Brooks, 1987].
- U.S. Department of Interior program for dissemination of real time oceanographic data for public use and to develop an improved description and understanding of ocean circulation using direct and indirect current measurements of the continental shelf from Northern California to Oregon [Ryther *et al.*, 1988].

2. Direct measurements of velocity fields.

Direct measurements of ocean circulations are obtained using recording current meters moored at fixed locations or from drogue and drifting buoys. Current meters not only measure velocity and direction, but can also measure temperature, pressure and conductivity. Moored systems usually have several recording current meters vertically spaced in the water column. The data sample rate is user selectable from minutes to hours and is stored in a self contained recorder until the mooring is recovered. Moored instrumentation only provides information on physical parameters of the ocean at a given location at a given time, and experience indicates that large variations in the velocity field can occur over small distances as well as over small time intervals [Pickard

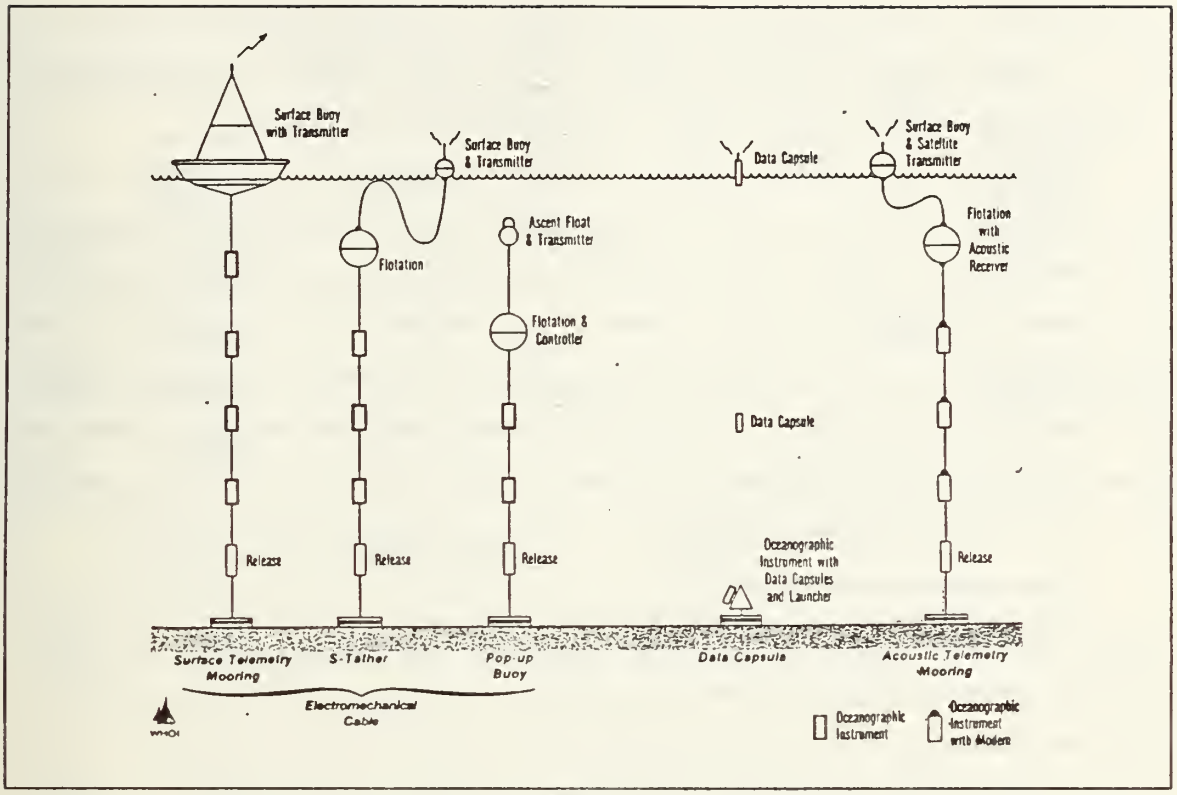


Figure 1. **Technical Approaches to Telemetry Buoys (Frye, 1987):** Some of the technical approaches for data transfer from in situ oceanographic instruments are illustrated. A thesis objective is to combine the pop-up buoy with the acoustic telemetry buoy system.

et al., 1982]. The moored recording current meter systems are expensive both in terms of the instrumentation cost and the cost of launch and recovery of the systems. As a result, only a few institutions are involved in direct measurements and as a consequence only a small proportion of the ocean has been observed by direct measurements using current meters.

3. Telemetry options for oceanography.

Recovery of oceanographic data in near real time from buoys requires a telemetry system. Many possibilities exist: subscriber systems using polar orbiting satellites, such as NOAA/ARGOS systems or geostationary satellites. The various types of geostationary satellites include GOES/GMS/METROSAT/ATS systems. Non-subscriber systems consist of high frequency (HF) for long range radio propagation, very high frequency (VHF) and ultra high frequency (UHF) for line-of-sight propagation and meteorburst for linking stations to 2400 km. Figure 2 illustrates the telemetry options

for oceanographic measurements from offshore buoys. Nearshore telemetry is the least costly of the systems, because the line-of-sight non-subscriber systems can be employed.

4. Telemetry methods to recover direct measurement data in real time

Telemetry system designs vary as a function of physical and economic constraints. Physical constraints involve the propagation path of the transmitted signal to the shore station, which dictates the physical size and electrical power limitations of the remote system. Economic constraints relate to the availability and/or adaptability of system equipment, user fees (if subscription is made to a telemetry service), packaging of the system and transportability of the finished system. Whatever telemetry system is designed, the prime concern is adequate data throughput in near real time. Reliability of data throughput is a function of system selection and planning.

System selection and planning involves selecting the optimum telemetry operating frequency, operating mode of the telemetry system and selecting equipment hardware and software. There are, of course, many telemetry schemes of varying complexity, cost and usefulness which can be developed, but as a minimum, all systems must take into consideration the area coverage, maximum transmission path expected, terrain considerations along the path and the level of reliability required for data throughput. The design objective of this thesis is the development of a survivable telemetry system for near real time data collection from a near shore moored buoy system. The proposed telemetry system for this thesis supports a line of moored buoy systems perpendicular to the coast and extending seaward 28 nm. The shore station elevation is 350 ft, which provides a radio line-of-sight out to the farthest buoy antenna, which is elevated to 7 ft.

The effectiveness of radio line-of-sight telemetry depends on the selection of frequency and the modulation scheme. The electromagnetic spectrum is classically divided into seven sections as seen in Table 1.

Telemetry Tradeoffs for Oceanographic Measurements from Offshore Buoys

Telemetry Option	Coverage	Typical Throughput	Power Requirement	Platform Location	Hardware	Costs Per Month	Costs Per Bit	Long-Term Availability	Receive Station
ARGOS	Worldwide[a]	0.02-0.2 bps	1-10 J/bit	+/- 1 km +/- 1 km N/A	$2k	$820[b,c] $236[b,c] $102[b,c]	$0.0014 $0.0004 $0.002	Yes	Not Required, But Available ($40k)[d] With Limited Coverage[e]
ATS	Hawaii to Azores, But Non-Polar	0.3-1.2 kbps	0.5-1 J/bit	N/A	$6k	0	0	No	Not Required, But Available ($5k)
GOES/METEOSAT/ GMS/INSAT	Worldwide Except Polar Regions	0.2-2 bps	1-2 J/bit	N/A	$3k	0	0[f]	YES	Not Required, But Available ($40k)
VHF (Line-of-Sight)	10-50 km from Receive Station	0.3-1.2 kbps	0.02-0.1 J/bit	N/A	$1-2k	0	0	Yes	Required ($5k)
Meteor-Burst	2000 km from Master Station	1-20 bps	0.2-1 J/bit	N/A	$5-10k	0	0	Uncertain Due To Licensing	Required ($100k)
HF Packet	Variable Up To Worldwide[g]	1-30 bps	1-10 J/bit	N/A	$2k	0	0	Yes	Required ($10k), May Need Several[d]
Future[g]									
Inmarsat Standard-C	Worldwide Except Polar Regions	10-100 bps[h]	0.5-1 J/bit	N/A	$5-10k	0	$0.00125[h]	Yes	Not Required
Geostar	Coastal U.S.	0.1-10 bps[h]	0.01-0.1 J/bit[i]	+/- 7 m	$3k	$45	$0.00016	Not Known	Not Required

NOTES:
(a) Not continuously; orbiting satellite.
(b) Basic charges are monthly; per bit charges are based on assumed data throughout. Many users get large (to 100%) discounts.
(c) Extra cost are required to obtain data via telephone or tape.
(d) See Figure 2.
(e) Lower data rates, more power required at longer ranges.
(f) More receive stations increases efficiency.
(g) Systems will exist by 1988.
(h) Estimates.
(i) Spread-spectrum technology, hence low power requirement.

Figure 2. Telemetry Cost and Throughput Options (Frye, 1987): This thesis uses the *VHF (line-of-sight) telemetry option.* It is the least expensive system and, although it requires some skill to assemble, it requires little skill to operate. This thesis details the assembly and operation of a VHF NBFM packet telemetry system for use in near shore applications.

Table 1. RADIO SPECTRUM DIVISIONS: This table equates the short titles for frequency to spectrum coverage.

FREQUENCY ALLOCATION	SHORT TITLE	SPECTRUM COVERAGE
Very Low Frequency	VLF	3-30KHz
Low Frequency	LF	30-300Khz
Medium Frequency	MF	300-3000KHz
High Frequency	HF	3-30MHz
Very High Frequency	VHF	30-300MHz
Ultra High Frequency	UHF	300-3000MHz
Super High Frequency	SHF	3-30GHz

Minimum interference from beyond line-of-sight sources requires the spectrum coverage to be VHF or higher. Below VHF, propagation is a function of solar radiation

which develops and controls the strength of layers in the ionosphere. Ionic layers develop at various elevations in the ionosphere, depending on the time of day and latitude, permitting lower frequency wavelengths to refract back to earth as a skywave. Skywave propagation greatly exceeds line-of-sight and can propagate around the globe. The ionosphere can also absorb lower frequency wavelengths during periods of solar flares. When the sun becomes too active, the ionosphere becomes over-excited and absorbs rather than refracts or reflects radio waves. VHF wavelengths are too short to be refracted by the ionosphere, but can, however, be refracted by moisture gradients in the atmospheric boundary layer and produce extended propagation called *ducting*. The minimum level of interference for various frequencies can be found in Figure 3. Interference is classified as noise which can come from other transmissions, man-made static, atmospheric static, cosmic emissions and receiver temperature-induced noise.

Modulation schemes also improve interference rejection. Two primary modulation schemes are used: amplitude modulation (AM), and frequency modulation (FM). AM varies the amplitude of the transmitter's fixed frequency. FM varies the transmitter's frequency at a fixed amplitude. Basically, AM has a bandwidth which is twice the modulation frequency (frequency plus modulation is called the upper sideband and frequency minus the modulation is called the lower sideband). AM is primarily used below VHF because of its very weak signal preformance and the spectrum conservation of the AM bandwidth, but AM is subject to any noise amplitude modulations caused by other transmitters in the same bandwidth, atmospheric static, man-made static, etc.. FM has a bandwidth which varies non-linearly with the modulation frequency. Narrow band FM (NBFM) has about the same bandwidth as an AM transmission. Wide band FM (WBFM) can have bandwidths up to 10 times the modulating frequency. Since FM uses frequency deviations and not amplitude variations for demodulation of the signal, *limiting* (a method of clipping the excess signal which contains amplitude variations) can be used on the received signal to remove amplitude noise. The non-linear nature of FM results in less efficient spectrum conservation and, therefore, is used for VHF and higher frequencies.

FM's insensitivity to noise is a positive feature, as long as sufficient receiver gain is available to ensure limiting. A second interference rejection mechanism is called *capture*. Capture effect is the ability to lock-on to only the strongest signal. The received signal will be interference free while captured and becomes uncaptured only when the interfering signal becomes as strong as the desired signal. As a result, FM has a decided advantage over AM in overcoming crosstalk and intermodulation products from

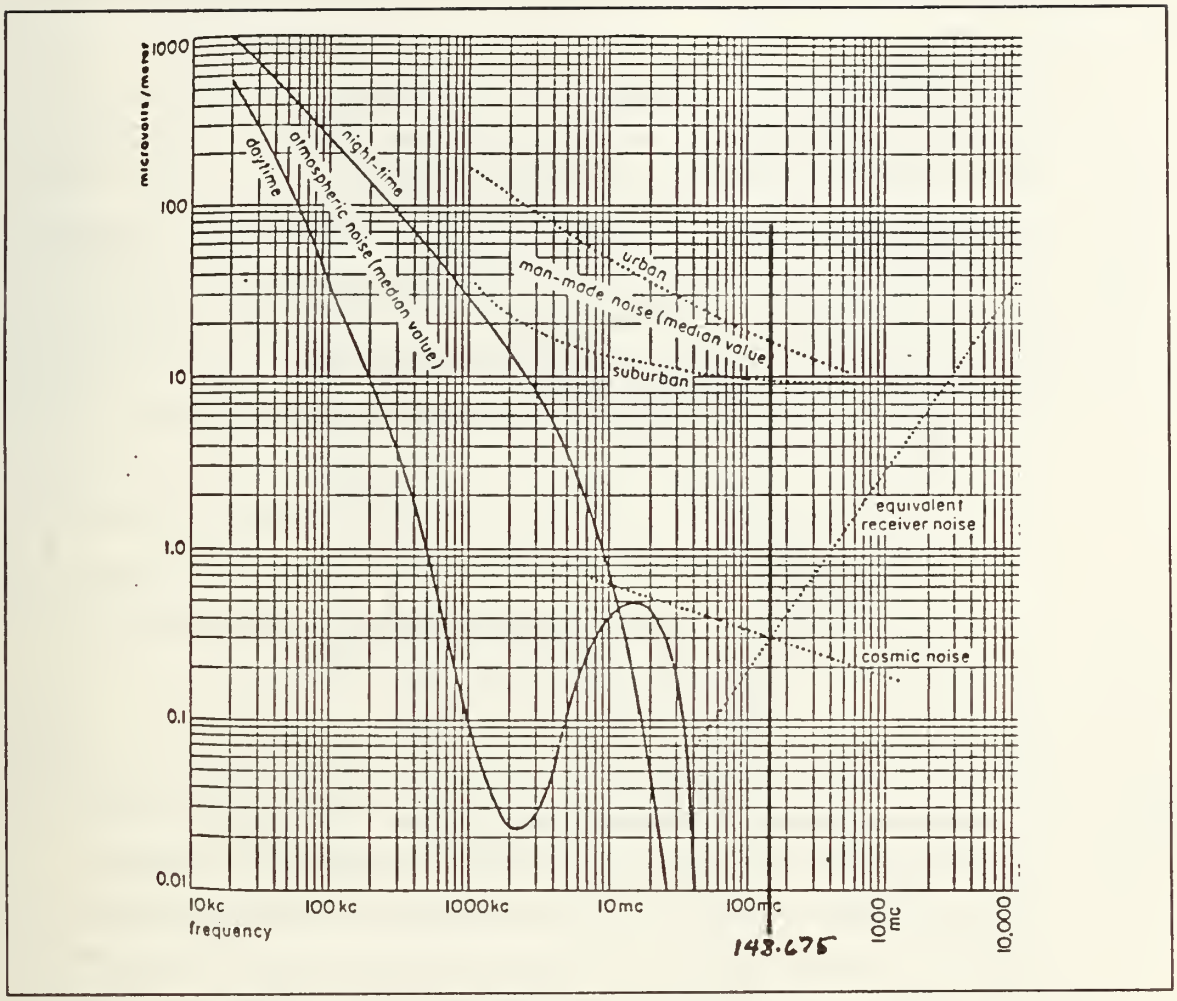


Figure 3. RF Noise in microvolts/meter vs Frequency (ITT, 1957): This project will operate on a Navy designated frequency of 143.675 MHz, which is in the spectrum area of low atmospheric noise, non-urban and low man-made noise environment.

other nearby frequencies. FM loses its advantage over AM (Figure 4), only under very weak signal conditions. Normal propagation for VHF is line-of-sight and very weak signal conditions for line-of-sight usually are not encountered in properly designed FM systems. When the signal-to-noise ratio is less than 1, the noise can be captured over the signal, but in AM, the signal just becomes weaker, with detection remaining possible.

The advent of digital communications and microcomputer error checking protocols has added a new dimension to reliable transmission of data between multiple

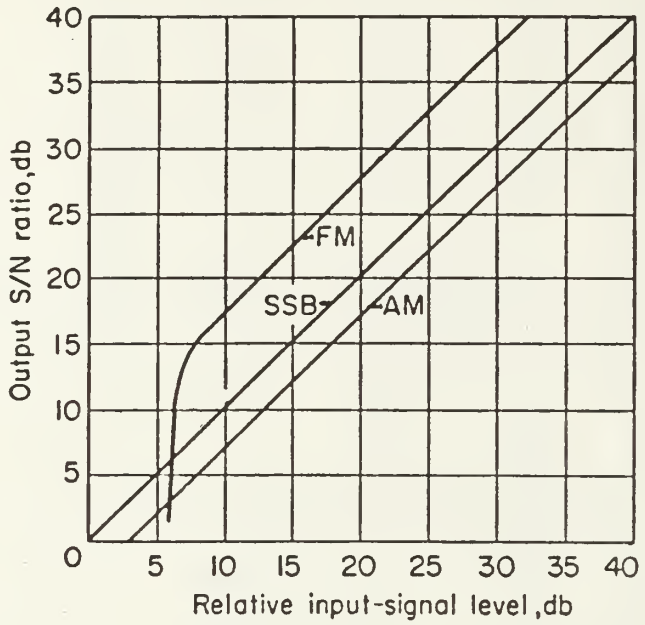


Figure 4. **Modulation advantages (Pappenfus et al., 1964):** Modulation schemes vary in sensitivity to noise and in bandwidth occupation. In strong signal environments (SNR > 15 db), FM, especially wideband FM, have excellent noise resistance, but at the cost of larger bandwidth usage due to the non-linearity associated with FM schemes. This also results in FM not being frequency conserving enough for HF. AM schemes are frequency conserving, but more sensitive to amplitude noise. In very weak signal conditions, the *capture* feature and phase modulation distortion from noise significantly reduce the FM advantages.

stations. By combining high speed microprocessors, memory and a system protocol with low baud rate equipment, the low data rate equipment can be multiplexed with computer error checking code and telemetered at a higher baud rate in the form of individual *packets* of information. Each individual packet of data contains its own error checking codes and additional codes to indicate where in a message the data is to be addressed. As a result, packets of data can be separated and transmitted by any means to reach the

final address. The receiving station contains the same microprocessor protocol system and will assemble the packets in the correct order. If the receiving station detects an error, or is missing a packet, it will interrogate the transmitting station for a retransmission of a missing packet and will continue this process until the data is received error free. The data information content in each packet can be adjusted to meet propagation or environmental conditions, such as propagation fading in HF or ocean wave motion affecting the antenna on a VHF telemetry buoy. This system of digital communications has become known as a *store and forward packet switching network* or just *packet* for short. The term packet was coined in 1965 by D.W. Davies of the British National Physical Laboratory, [Horzepa, 1988].

The system selection and planning involved to develop telemetry for near shore moorings is discussed in detail in the next section.

B. SCOPE

1. Requirement for real time telemetered data

The Naval Postgraduate School (NPS) is conducting a five year research program on the California Undercurrent off central California. The features of the California Undercurrent, and formation of jets and eddies are not well understood. Information is needed to determine their extent, strengths, and core structure, and to answer how and why the features vary by location and season, and what atmospheric phenomena, such as wind variations, influence subsurface features. With a real time telemetry system providing data from current meters, any variability noted can be immediately investigated using satellite imagery, ship cruises and weather buoy data.

The Naval Enviromental Prediction Research Facility (NEPRF), in Monterey, CA., is developing a capablity to collect and archieve high resolution data from polar orbiting satellites. The data will be Sea Surface Temperature (SST), DMSP Microwave Imager (SSM/I) and Advanced Very High Resolution Radiometer (AVHRR). NEPRFs' interest is to provide the ability to conduct time series research along the California coast using SST, SSM/I and AVHRR data (Boyle, 1989). An adequately instrumented grid of telemetered current meters aids in the utilization of satellite data and will allow (Robinson *et al*, 1986):

- For the first time, a real time dynamical forecast of the oceanic undercurrents, jets and eddies.
- Development of the methodology of nowcasting, forecasting and data assimilation.
- Development of methods of dynamically interpreting direct measurements of the physical fields in nearshore regions.

The present NPS system design is an array of recording current meters deployed and recovered at six month intervals. The proposed mooring sites are as shown in Figure 5. The recording current meter being used, the Aanderaa Instruments recording current meter model RCM8, sequentially records six 10 bit binary words: a unit reference number, instantaneous measurement of temperature, conductivity, and pressure, and vector averaged current direction and current speed at a preselected interval (0.5, 1, 2, 5, 10, 20, 30, 60 or 120 minutes). The recorder has a maximum record storage capacity of 10,900 records, each containing 61 data bits. Table 2 indicates the maximum deployment time for each recording interval.

Table 2. RECORDING CAPABILITY OF AANDERAA RCM8 CURRENT METER

Record Interval (minutes)	Records Per Day	Bits Per Day	Maximum Deployment Period(days)
120	12	720	908
60	24	1440	454
30	48	2880	227
20	72	4320	151
10	144	8640	75
5	288	17280	38
2	720	43200	15
1	1440	86400	7.5
0.5	2880	172800	4

The minimum RCM8 recording interval for a six month deployment is every 30 minutes. This equates to 2880 bits of data per day. The RCM8 is equipped with an acoustic telemetry system using a 10-bit pulse duration code at 37 baud. Acoustic telemetry is received with an *Aanderaa Instruments hydrophone receiver 2247* which converts the 16384 HZ pulse duration code (PDC) format to an on-off keyed carrier of 0 volt pulses for a 27 ms PDC and -6 volt pulses for a 81 ms PDC. The voltage pulses represent a 0-bit for 0 volts and 1-bit for -6 volts. Each measured parameter is a 10 bit word, 6 measured parameters make up a record, and each record has a sync pulse for a total of 61 bits per record. A hardwire connection to the current meter can be made via the *2924 electric terminal.* The acoustic interface capability has been researched by Frye of

WHOI who has shown the Aanderaa hydrophone to be less than optimum for reliable data recovery beyond a 100 meters depth separation between the hydrophone and the RCM8. Testing conducted as part of this thesis at sea (chapter 4), off of Point Sur, CA, confirm that error rates significantly increase beyond a 80 m depth separation between the hydrophone and the RCM8. An improved error checking hardware and software system was developed, but was unable to overcome the acoustic path limitations of the hydrophone or the RCM8. Even with the Aanderaa hydrophone error rate limitation, the available data can be exploited for radio telemetry of whatever acoustic signals the RCM8 sends. If data from the RCM8 can be processed once per day, then a near real time analysis of data can be achieved and the advantages summarized previously could be realized. The fact remains, the Aanderaa acoustic equipment is the weak link to an effective data recovery system.

URIP (Frye, 1987) is evaluating an improved acoustic data link for transmitting data vertically from a moored instrument array to a surface buoy. URIP will set a specification for acoustic modem design and solicit the URIP organization and commercial vendors to submit acoustic modems for testing. This research effort should provide an improved acoustic link for interfacing with this project's telemetry system.

2. Design considerations to meet requirement

a. Near shore buoy system strategies

(1) Pop-up buoy design goals. The initial design proposed is a buoy which can survive the environment of the sea (shipping, fishing activity and the sea environment). Surface riding buoys are physically large, because of the requirement to support safety of navigation aids such as lights, radar reflectors and batteries. State-of-the-art telemetry systems for line-of-sight systems are solid state and small in size. Removing the navigational aids leaves the contents of any line-of-sight telemetry system in a small enough package to consider evaluating a pop-up buoy package, which surfaces once a day to transmit the stored data at a high data rate and resubmerges.

The proposed pop-up buoy system would consist of a submerged platform at 30 meters beneath the water, providing clearance for deep draft vessels. The submerged platform would be the highest section of a fixed moored recording current meter system. It would contain the Aanderaa hydrophone receiver, data collecting computer, packet terminal node controller (TNC), batteries, winch and a haul-down reel. Batteries for the system would have the capacity to cycle the winch once per day for a six month deployment. A Kevlar cable, with two pairs of 28 gage wires would link the pop-up buoy to the submerged platform. The buoy package would house the VHF

STATION	LATITUDE	LONGITUDE	DEPTH	DISTANCE OFFSHORE
P1	36 20 N	121 58.5 W	100 M	7.5 KM
P2	36 20 N	122 10.5 W	800 M	25.0 KM
P3	36 20 N	122 28.3 W	1800 M	52.0 KM

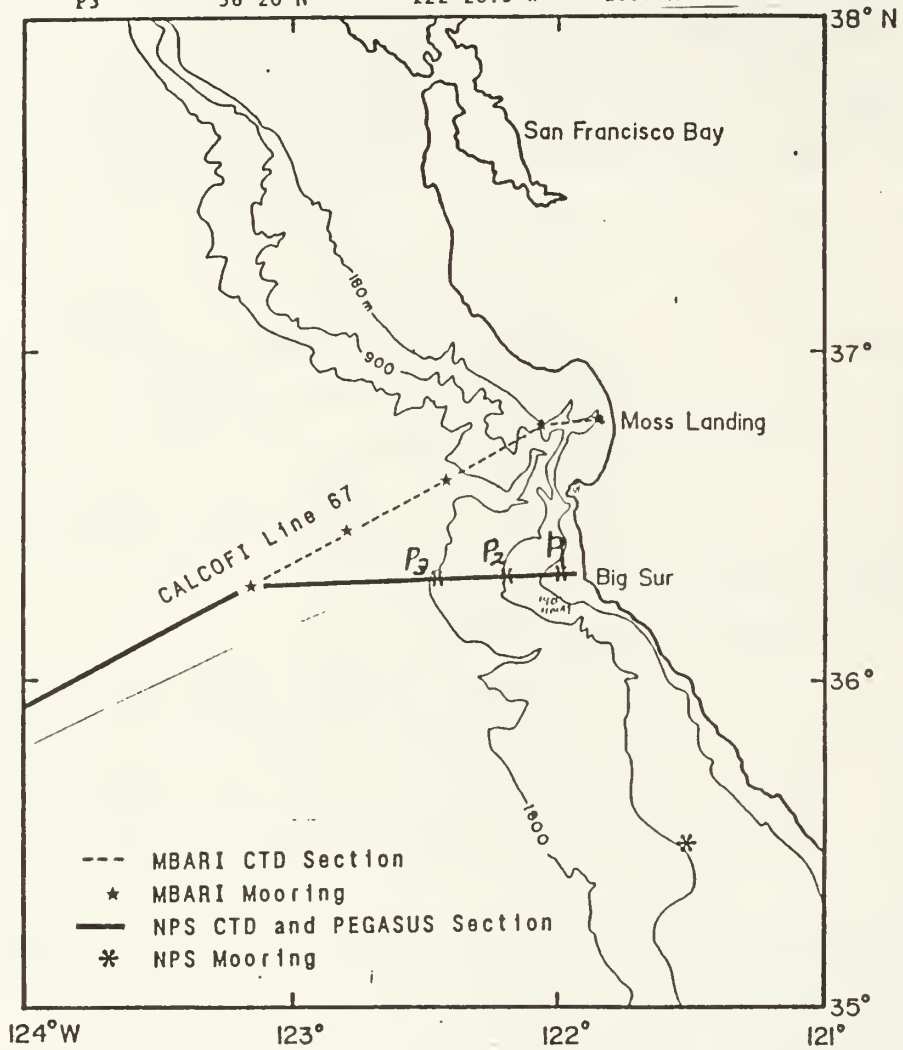


Figure 5. Transect Mooring Positions off of Point Sur, CA: The project uses mooring stations P1, P2, and P3. Station P1 and P2 are well within the free path propagation for VHF radio line-of-sight telemetry. Station P3 is at the edge of the free path propagation limit.

transceiver, a VHF preamplifier, batteries and antenna. The buoy would surface once per day to transmit the daily record of 2880 bits of data per current meter attached to the mooring. The TNC has a data rate transfer of 1200 bits per second, but the data is transferred in packets of 1196 bits (128 data bits times eight plus another 172 bits for error checking and addressing overhead). A minimum of 23 transmissions are required to send 2880 bits of data in the error free format (2880 data bits/128 data bits transmitted = 23 transmissions). Total telemetry time is a few minutes and depends upon how many retransmissions are required to clear all telemetry errors. After the final transmission the buoy would be resubmerged.

This thesis will demonstrate that a pop-up buoy system is possible because of the small size of the buoy package. The pop-up buoy system will improve the survivability of the buoy against shipping traffic. Figure 6 is a typical shipping density plot for the area off of Point Sur, where this research project is being conducted. The short duration on the surface will limit accessibility to the buoy by other small craft. Pop-up timing can potentially avoid predictable environmental conditions, especially times of near shore maximum winds.

(2) Simplicity of design. Design of the telemetry system is based on existing commercial equipment rather than a full scale ground up design. Equipment is selected based on adaptability and minimum interfacing requirements. Selection of equipment also requires that several manufacturers make the same type of equipment, to ensure future adaptability for interchanging components with little or no modification. The software used for the telemetry protocol is the AX.25 protocol. This protocol is the same used by WHOI, MIT and Texas A&M for their telemetry systems. AX.25 is a modified commercial protocol CCITT X.25 used as a standard in computer to computer modem communications. The amateur radio community modified the CCITT X.25 protocol to allow multiple connections and multiple retransmissions though repeaters called *digipeaters.* The single board computer uses a generic basic language, making programming changes simple and understandable.

(3) Commercially available hardware. Hardware selection is based on high volume markets where several manufactures are involved in the same type of product. The buoy and shore VHF NBFM transceivers and TNCs are common amateur radio equipment, which are also manufactured for commercial applications. The selected transceiver for the buoy is an ICOM 02AT, 5 watt, hand-held unit that can transmit between 140 MHz to 150 MHz and for the shore station, an ICOM 27A, 25 watt, unit that can also transmit between 140 MHz to 150 MHz. Both of the transceiver

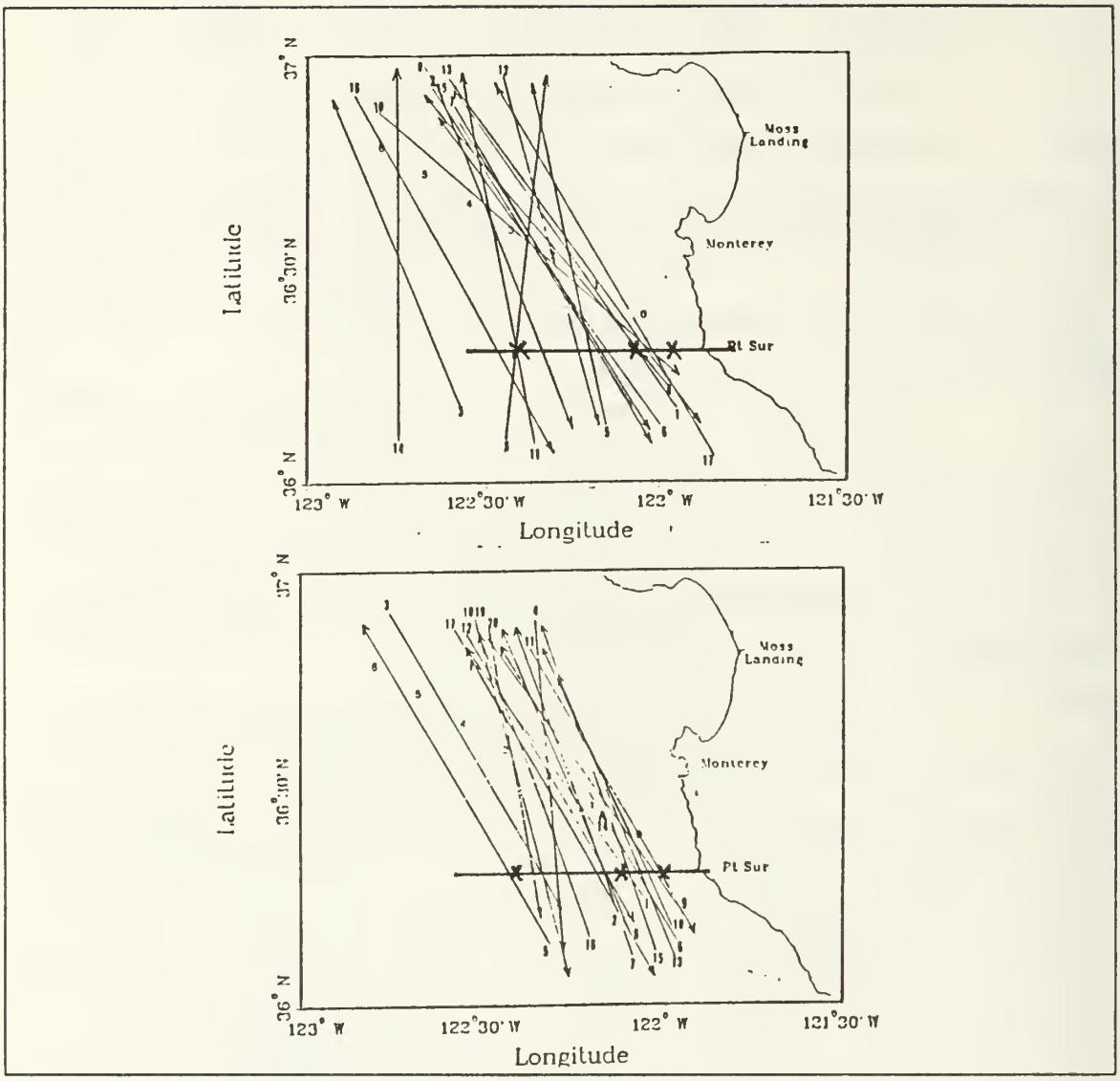


Figure 6. Typical Shipping Density for the Point Sur Mooring Site: The shipping density observed for two different three day periods over the transect site (3-5 June 86 and 5-7 August 86).

models have been accepted by the Navy for use in the project on an assigned frequency of 143.675 MHz. The TNCs are generic Tucson (Arizona) Amateur Packet Radio Corporation (TARP) TNC2 protocol units, which are the standard for amateur radio and becoming a standard for commercial radio systems using digital data transfers at 1200 baud. The single board computer selected is a Tattletale Model IV data logger computer by Onset Computer Corp. (N. Falmouth, MA).

(4) Low cost. Unit cost of components is always an important factor. Components with established volume markets help to ensure lower costs. Amateur radio equipment is very sophisticated and at the leading edge of communications technology, while remaining at a low cost relative to commercial grade equipment. TNCs were manufactured by amateur radio operators to keep the costs low and commercial manufacturers who support amateur radio have kept their commercial production of the TNCs at a low cost to both the amateur and commercial users. Appendix A is the price list for the major components purchased for this project.

(5) Low power. A six month deployment of the buoy system requires that the power consumption be as low as possible to keep the weight and size of the system small. The computer and the hydrophone receiver are designed to be operational for the duration of the deployment. The transceiver and preamplifier require only about 5 minutes of power during the daily telemetry transmissions. CMOS integrated circuit equipment is selected because of its low power consumption capability. The Onset computer draws 2 ma at 12 volts during inactive periods and about 15 ma during periods of computation and data storage. The TNC consumes 40 ma during the telemetry phase and the transceiver and preamplifier consume 150 ma during telemetry receive and 1300 ma during telemetry transmit. When not in the telemetry mode the TNC and the transceivers are off. The Aanderaa hydrophone operates continuously at 3 ma. Power consumption for a six month deployment, using conservative estimates are as follows:

- Computer (5 ma x 24 hours x 180 days = 21.6 amp-hours at 12 volts)
- Hydrophone (3 ma x 24 hours x 180 days = 13 amp-hours at 9 volts)
- Telemetry (1000 ma x 1 12 hour x 180 days = 15 amp-hours at 12 volts)

An evaluation of various battery types was conducted to determine which battery type would be the most effective for each system (chapter 4).

(6) Buoy configuration types. Direct measurement systems for fixed moored recording current meters are primarily configured with either a surface buoy for telemetry of data, or a submerged buoy which requires recovery of the mooring to analyze the recorded data.

The pop-up concept, in this thesis, is a combination of the pop-up buoy and the acoustic telemetry mooring system of Figure 1. Only the electrical design to support the pop-up buoy concept is developed, leaving the mechanical design for the pop-up as a topic for further research.

b. Procedure for automated telemetry

The heart of an automated system is a computer that can keep track of time and ability to sequence other equipment in response to programming and external signals. The Onset Tattletale Model IV contains an internal counter that is incremented every 1/100 of a second, and uses a clock variable that is incremented every 10 ms. The clock variable counts in hundreds of seconds and overflows at about 200 days. Programming of the clock variable can provide time and date of occurrences of events and can also cause events to take place. On shore, comparing telemetry transmission time to the computer's telemetered clock variable time will provide a relative measure of the computer's time stability.

This automated system is preprogrammed to have two main functions.

(1) The first is to monitor the Aanderaa hydrophone receiver for pulses. The hydrophone only sends out 27 ms and 81 ms pulses on triggers of 16,384 Hz noise, either spurious or intentional. Intentional transmissions are in a definite sequence and time spacing. The computer is programmed to differentiate spurious signals from sequential hydrophone signals. Once an intentional signal is stored, the computer will stop monitoring the hydrophone for 75% of the interval timer setting preset in the RCM8.

(2) The second function is the telemetry of data to the shore station. When power is applied to the Onset, the stored computer program (which remains in memory when power is off for up to 6 months due to a 3 volt lithium battery) is executed. The start date is 1 1 80 at 0000.001 hours, unless changed at the time of power up via the RS232 port. On power up, initialization sequences are programmed to set variables and start the once per day telemetry. With 16 input/output digital ports and 11 analog to digital channels, the automation can be quite elaborate. The present arrangement uses the digital input/output lines to: 1) turn on and off the VHF transceiver and preamplifier and TNC, 2) look for packet *connected* signals and packet *acknowledge* signals from the TNC, 3) look for hydrophone receiver inputs. One analog to digital channel is used to measure the transceivers signal to noise level during the evaluation period. Future analog to digital connections can be used to measure internal battery voltages or any other environmental parameters which may be desired.

Details on the particular automation features are discussed in greater detail in the sections to follow.

c. Review of reasons for selecting VHF NBFM packet telemetry

Previous sections contained an overview of considerations for selecting line-of-sight telemetry. This section reviews in greater detail the technical considerations for why telemetry on the VHF spectrum, using NBFM with the packet data transfer mode, is the best modulation scheme for line-of-sight communications to near shore buoys. It is important to understand the technical considerations so future modifications have a benchmark to deviate from when making decisions to change frequency, modulation scheme or the data transfer mode.

The URIP is tasked to evaluate various high data rate telemetry schemes for getting data from a surface buoy to shore. They intend to develop new technologies (Frye, 1987). By providing sufficient detail on the technical considerations for this project, changes can be addressed rationally.

(1) Technically sound. Under the URIP program at WHOI, the telemetry project team experimented with a digital packet radio link on an assigned VHF channel of 148.450 MHz. This frequency is just outside of the amateur radio band of 144 to 148 MHz. The amateur equipment is inexpensive, easily attainable and is capable of operating between the frequencies of 140 to 150 MHz. Packet TNCs, which were developed by the amateur radio community, were also purchased and used. (Briscoe *et al.*, 1988)

Preliminary experiments by Brooks (1983), found VHF telemetry systems well suited for use in near shore applications. He found the equipment to be inexpensive, relatively simplistic and found to have widespread applications to open ocean as well as near shore ocean studies. The real time capability afforded by this equipment has a definite advantage for accessing data and monitoring instrumentation welfare. His experiments demonstrated how the real time feature is very useful in showing unexpected current fluctuations. The experiments involved VHF NBFM equipment, and used the 37 baud signal from the Aanderaa current meters to audio frequency shift key (AFSK) the NBFM transmitter. He was concerned with under utilizing the receiver bandwidth. Shannon capacity theory (Schwartz, 1970) addresses this efficiency as channel capacity (bits second), which is limited by bandwidth (Hz). The signal strength has additive Gaussian noise as follows:

$$C = W \ln(1 + SNR)$$

Statistically, the closer the bandwidth(W) is to the channel capacity (C), the lower the signal to noise ratio (SNR) can be and still maintain a virtually error-free digital transmission. This theory indicates that a linear increase in bandwidth, while maintaining a constant channel capacity and constant Gaussian noise level, results in an exponential reduction in the required signal strength. By using packet with 1200 baud AFSK to modulate the NBFM transmitter, the signal bandwidth approaches the receiver bandwidth, resulting in efficient bandwidth usage.

(2) Operating frequency and frequency allocation. Line-of-sight telemetry is optimized by using the VHF spectrum for the following technical reasons:

- Lowest interference (noise) is in the 140-150 Mhz Spectrum [Figure 3].
- Free-space transmission attenuation (α) is a function of frequency and distance [Hamsher, 1967]. Figure 7 is a nomogram of α. This shows that for a given distance, the higher the selected telemetry frequency the greater the line-of-sight attenuation.

$$\alpha = 33 + 20\log(Freq) + 20\log(Miles)$$

Note: Additional losses occur when the curvature of the earth is between the two antenna line-of-sight paths, see Fink, 1957, for losses beyond the line-of-sight.

For the above reasons a frequency allocation was requested and approved in the 140-150 MHZ spectrum. This frequency spectrum has an added advantage that inexpensive telemetry equipment is also available for the 140-150 MHZ spectrum.

(3) Signal to noise (SNR) environment. Maximizing SNR attempts to get the maximum information with the least degradation from noise. This is done by several methods, the simplest being to increase the transmitter power. This can be done only if you can afford the exponential demand on electrical power. Additionally, Shannon capacity theory statistically states that if the channel capacity is fully occupied by data using a proper encoding scheme, then the SNR required is low. If the channel is not fully occupied, then a higher SNR is required to ensure error-free transmission. This demonstrates the relationships between linear change in bandwidth and channel capacity, to the exponential change in signal power. Finally, the choice of the modulation schemes affects SNR. Figure 4 illustrates that under equal carrier power, with 100% modulation and equal receiver noise figures, FM has the advantage over single side band (SSB) and AM. However, under very weak signal conditions the FM advantages are lost [Pappenfus *et al.*, 1964].

SNR is not always the most important requirement. Information systems use entropy as a metric for measuring the information content to be transmitted.

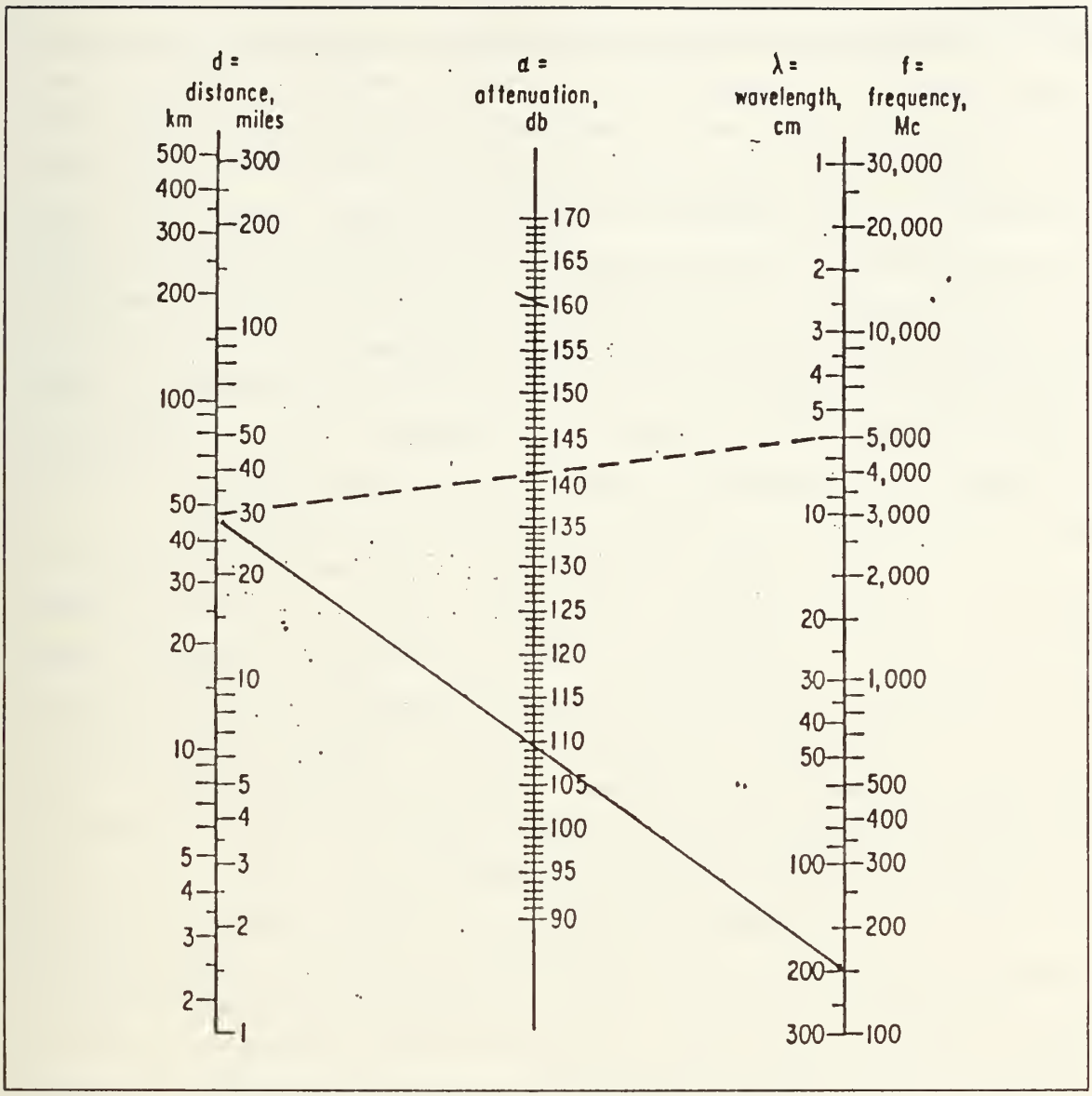


Figure 7. Nomogram for Solution of Attenuation α Between Isotropic Antennas (Fink, 1957): The most limiting contributor to line-of-sight operations is the height and distance between antennas. This nomogram illustrates the expected losses due to distance to the radio horizon line-of-sight. The solid line is the α for this design and the dashed line is an example of α at radar frequencies. The higher the operating frequency selected the great the losses.

Entropy is a statistical evaluation of information and the probability of uncertainty as to the outcome. The higher the entropy the lower the uncertainty in a system. As an example, the English language has a high entropy compared to a non-error checking

coded language. In the English language, as many as one third of the letters may be omitted and the message usually can still be determined. In a non-error checking coded message, however, even one missed letter can change or destroy the message. Consequently, redundancy is an important element used to combat the effects of lost signals due to poor SNR. SNR for this project is maximized by having the data rate capacity approaching the receiver bandwidth and using the FM scheme. Entropy is not an important consideration when using the packet error checking protocol, because the packet protocol can be adjusted to overcome either poor SNR or error rate by readjusting the transmission length and retransmission cycles. With packet, the low entropy of each packet transmission requires a noise-free environment, but the error checking system requests retransmissions if there are noise errors occurring. The error checking scheme now permits a low entropy system to operate in a higher entropy mode, with more tolerance for noise interference at the sacrifice of lower data rate throughput.

(4) Data transfer mode compatibility. Several methods are used to telemeter data. Analog data telemetry, the first method used for a long time, was subject to noise and drift. Improvements were made by converting analog signals to digital format, resulting in reduction of the noise and drift problems. Digital formats required a modulator and demodulator (MODEM) to improve transmission and reception of digital signals for direct input to computers. Modem designs require evaluation. Some modems operate efficiently in high noise environments and others do not. This is a design limitation and not a concept limitation. (Brooks, 1983)

The combination of microprocessors, memory, software and modems results in an error checking store and forward digital data protocol. Packet data transfers are part of this new technology. Packet was designed by the amateur radio community to operate at near the channel capacity of the receiver bandwidth. The result is that almost all VHF NBFM transceivers used by the amateur community are compatible with packet equipment.

(5) Equipment availability. Experiments to date by Brooks (Texas A&M) (Brooks, 1983), Briscoe (WHOI) and Frye (WHOI) (Briscoe and Frye, 1987), have found that telemetry systems can take advantage of the inexpensive amateur radio equipment, and use packet TNCs for an effective error-free, real time data collection system. Their applications focused on greater than line-of-sight telemetry. By using the refractive properties of the ionisphere for HF they could cover several thousand kilometers and by refractive properties of the marine boundry layer for VHF and higher frequencies they could take advantage of any trapping layers. This thesis will use the same types

of equipment, but will specialize on developing a reliable *line-of-sight only* telemetry system which is small in size, has low power consumption and is low in cost.

II. HARDWARE AND SOFTWARE DETAILS OF THE AUTOMATED DATA AND VHF NBFM PACKET TELEMETRY DESIGN

Project development focuses on small, light weight, low power and inexpensive equipment for use in a pop-up buoy designed to provide data from near shore moorings. URIP researchers are also investigating this same approach to develop similar system designs. The commercial market has various telemetry designs. ENDECO Inc., Marion, MA, sells an *"Adaptive Packet Telemetry System."* The ENDECO system works, but is not designed for use in a pop-up buoy system or for use in listening for Aanderaa current meters over an acoustic link. The software is proprietary and is not easily adaptable. Other companies, such as REPCO Inc. of Orlando, FL, will provide discrete equipment modules for developing systems using a fixed frequency and provide their own modem systems. Researchers in VHF telemetry are not becoming product specific, but are using public domain packet software and equipment developed by the amateur radio community. This project will discuss in detail the hardware and software interfacing for a single buoy and station, expansion of which only requires building more buoys.

A. BUOY SYSTEM PACKAGE

The basic telemetry package is illustrated in Figure 8. Illustrated is the buoy package and the shore station major components. The buoy contains a single board computer, packet TNC, radio transceiver, radio preamplifier, power supply, antenna and instrument package interface. The shore station uses a generic computer capable of RS232 interfacing, packet terminal node controller (TNC), radio transceiver, radio preamplifier, power supply and a high gain antenna.

The sequence of equipment operation is as follows:

- Single board computer on buoy stores data from the instrumentation package and controls the time of telemetry transmission (once every 24 hours).
- When the time for telemetry occurs, the computer turns on the TNC, transceiver and preamplifier. The computer then will initiate a telemetry connection loop to the shore station.
- The shore station is always monitoring for a connect sequence to a specific mooring or moorings identified in its program. Once connected the shore station accepts only error free data. If the data has an error, the shore station will request a retransmission of the data.
- The buoy computer checks the TNC to ensure all data has been sent and then initiates a system disconnect.

- The shore station disconnects.
- The buoy computer secures the TNC, transceiver and preamplifier on disconnect and resumes instrumentation monitoring.
- The shore computer remains on standby for future transmissions.

The remaining section details the individual components, software, functions and parameters used in the system development.

1. Automated data logger and system controller

The automated data logger is a single board computer made by ONSET Computer Corp. of N. Falmouth, MA called a Tattletale Model IV (TT4), (Figure 9). The TT4 has extensive versatility in a small package and low power requirements. The features of the computer are:

- 32K for programming, variables and storage
- 11 channel, 10 bit A-D ratiometric converter
- 2.25″ x 3.725″ x 0.8″ physical dimensions
- 2-15 ma at 9-12 volt power requirement
- Tattletale BASIC operating system (TTBASIC)
- Battery backed RAM

The only modifications required for use in this system are adding protective isolation circuitry and integrating the RS232 electronics from the RS232 interface cable (TC-4) on to the breadboard (PR-4). The protective circuit diagrams are illustrated in Figure 10.

The TT4 is easily programmed using any computer with a RS232 connection and a generic modem program. The program used for communicating with the TT4 is PC-TALK III (freeware program from an IBM PC public domain library). Communication parameters are 9600 baud, parity n, data bits 8 and stop bit 1. The TT4 is set to 9600 baud by executing the following line: X = 16 : ASMX,DB5. The 9600 baud is used to communicate between the TT4 and the TNC to maximize monitoring efficiency of the TT4. TTBASIC (a modified BASIC language) or assembly language can be used to program the TT4.

Programs used in this project are all written in TTBASIC. Appendices B, C, D, E and F are sample project related programs. File programs are stored in a PC-TALK III file, and can be up or down-loaded to the TT4. Once the program is loaded, the battery backed RAM will maintain the program for up to six months without

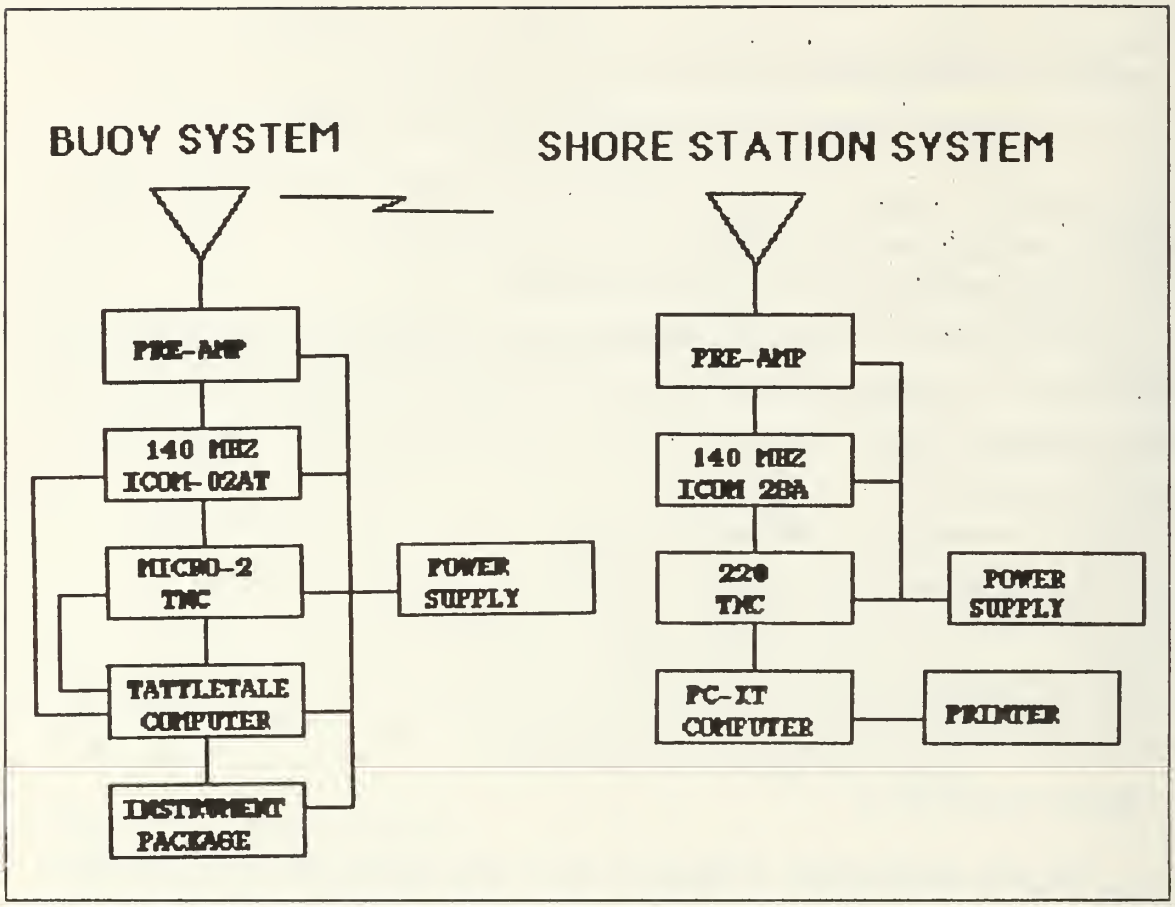


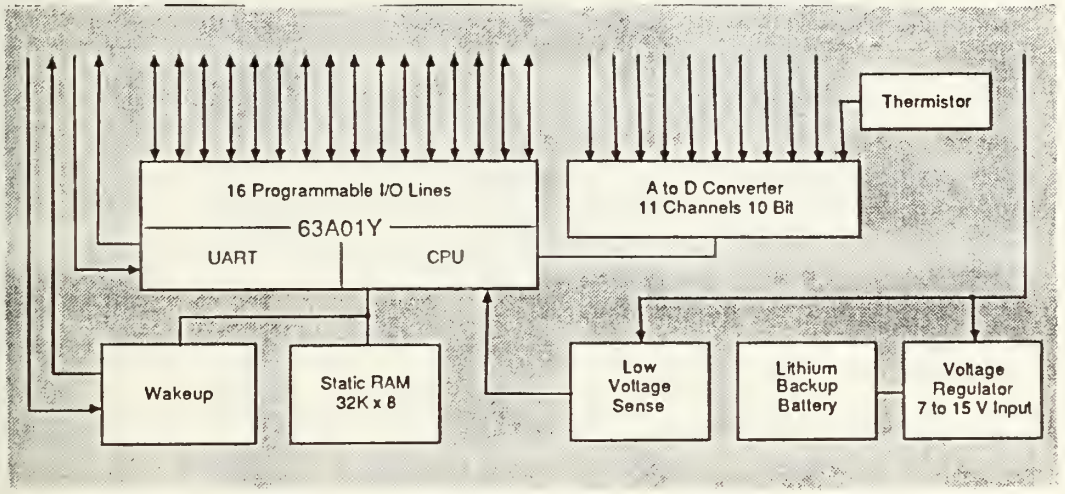
Figure 8. Block Diagram of the Basic Packet Telemetry System: Each block is an individual piece of equipment required for one telemetry net. This system can have 1 to 50 or more buoys interfacing with a single shore station.

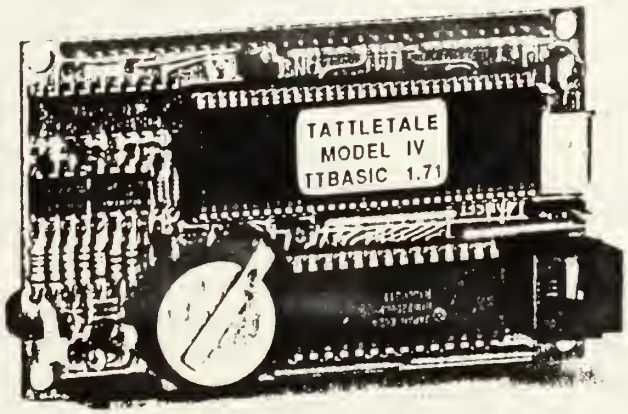
external power applied. On application of external power, the loaded program executes. Appendix B is the primary program listing, with remarks. When the program is loaded, the remarks are removed by the TT4. The system operating program is block diagrammed in Figure 11.

Hardware mounting configuration is illustrated in Appendix G.

2. VHF NBFM transceiver

The transceiver used in the pop-up buoy design is an ICOM-02AT (ICOM), from ICOM Inc., Osaka, Japan. It is a small, light weight, frequency synthesized, handheld transceiver. The specifications, listed in the Appendix H, are the typical pa-





Tattletale Model IV

Figure 9. Buoy Computer by ONSET: The TT4 is the automation controller for the buoy system. It is programmed in TTBASIC with a battery-backed RAM for initiating a program start-up, if power is remove and then re-applied.

rameters expected from most handheld transceivers used in the amateur and commercial applications. This particular transceiver was initially purchased, because it operates on any frequency from 140-152 MHz. Experimentation on the telemetry design was con-

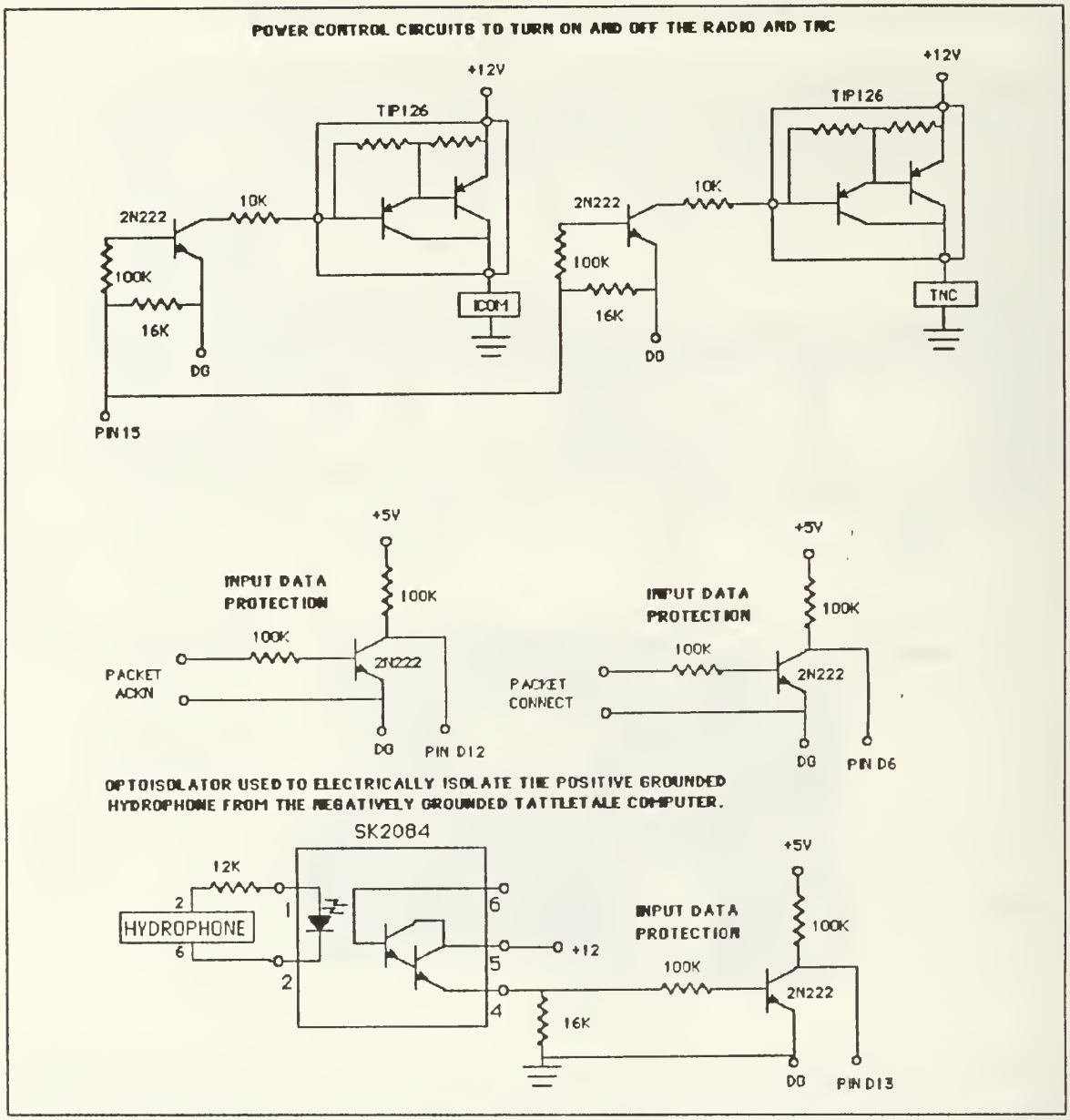


Figure 10. Protective Circuits Between TT4 and Interfacing Equipment.

ducted in the 144-148 MHz amateur radio band, while awaiting a designated frequency from the Navy. A frequency was requested between 140-150 MHz, and after eight months of processing by the Navy, an assignment of 143.675 MHz was approved. Appendix I, illustrates the requesting message and the approval message. Navy pulication NTP-6(B), Annex D, covers message formats and procedures. The ICOM-02AT and the

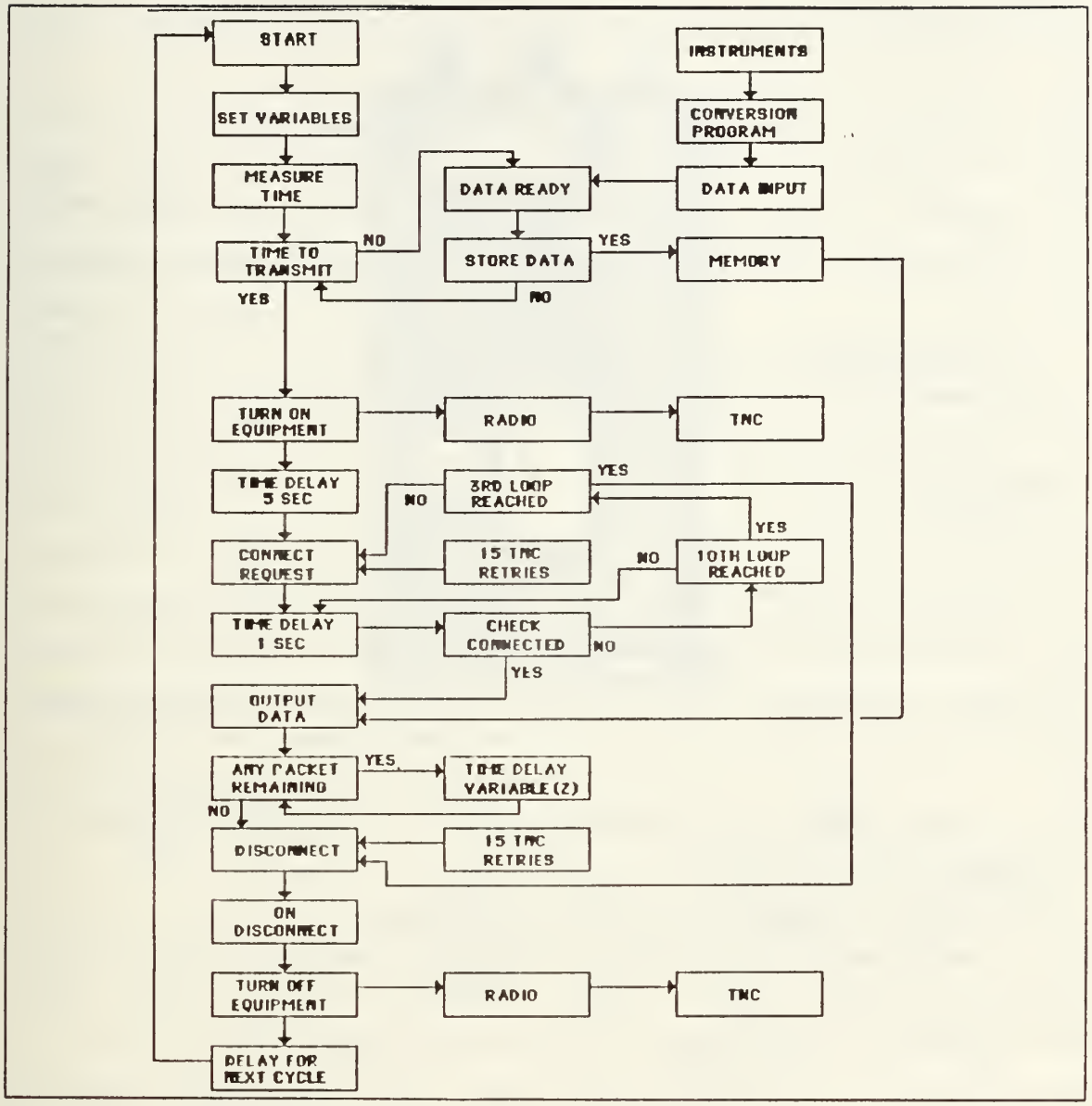


Figure 11. TT4 System Operating Program Block Diagram: System block diagram outlining the major program logic steps of the program in Appendix B.

shore station transceiver (ICOM-28A) are amateur radio equipment which the Navy has accepted for operation on military frequencies.

Several modifications are required to prevent malfunctions during deployment. All contacts and connectors are removed and replaced with soldered wire connections.

An additional connection was attached to the signal-to-noise (SNR) metering circuit for evaluation and performance testing. The SNR modification is worth mentioning, because is was used to verify system performance when design changes were made. The SNR was wired to an analog channel on the TT4 and by programming the TT4, SNR values were attainable. The SNR tap is shown at a point just before the limiter stage of the integrated circuit IC201 in Figure 12, between diode D202 and capacitor C201. At this wiring point a long jumper wire can be found, which runs across the bottom of the ICOM.

The ICOM control settings are preset as follows:

- Power on
- Volume between 70-100mv
- Squelch on
- Power setting high
- Frequency set and locked on 143.675 MHz (internal battery back-up)

Upon application of power from the TT4 (see Figure 10), the ICOM comes on at the proper presets. The preset that can be the most difficult to set is the squelch. It must be adjusted just high enough to cut out all the background noise. This can present a problem in that the setting in the lab and at the mooring site may be quite different and may require a pre-deployment check before launching the mooring (this has not been a problem for the Point Sur, CA site).

The ICOM consumes 35 ma during squelched receive and 1300 ma during transmit. Actual transmit power transmitted is a function of battery voltage. The higher the voltage the higher the power (13.8 volts = 5 watts and 7.2 volts = 1.5 watts). The ICOM operates only about 5 minutes per day. The test section discusses battery selection considerations for maximum power output under surge loading conditions. Hardware mounting configuration is illuatrated in Appendix J.

3. Packet terminal node controller (TNC)

The TNC selected for the pop-up buoy is from Packet Radio Systems, Inc. (Pac-Comm) of Tampa, FL and is called the Micro-2. This TNC was chosen based on its capabilities and in particular, because the CMOS integrated circuits only consume 40 ma. There are many brands available, but few operate at a power consumption as low as 40 ma. Most brands have large RAM capacity for the store and forward protocol function. This TNC has 32K RAM and will store the 9600 baud data from the TT4 during the power up period of the TNC. The TNC has multiple baud rate settings

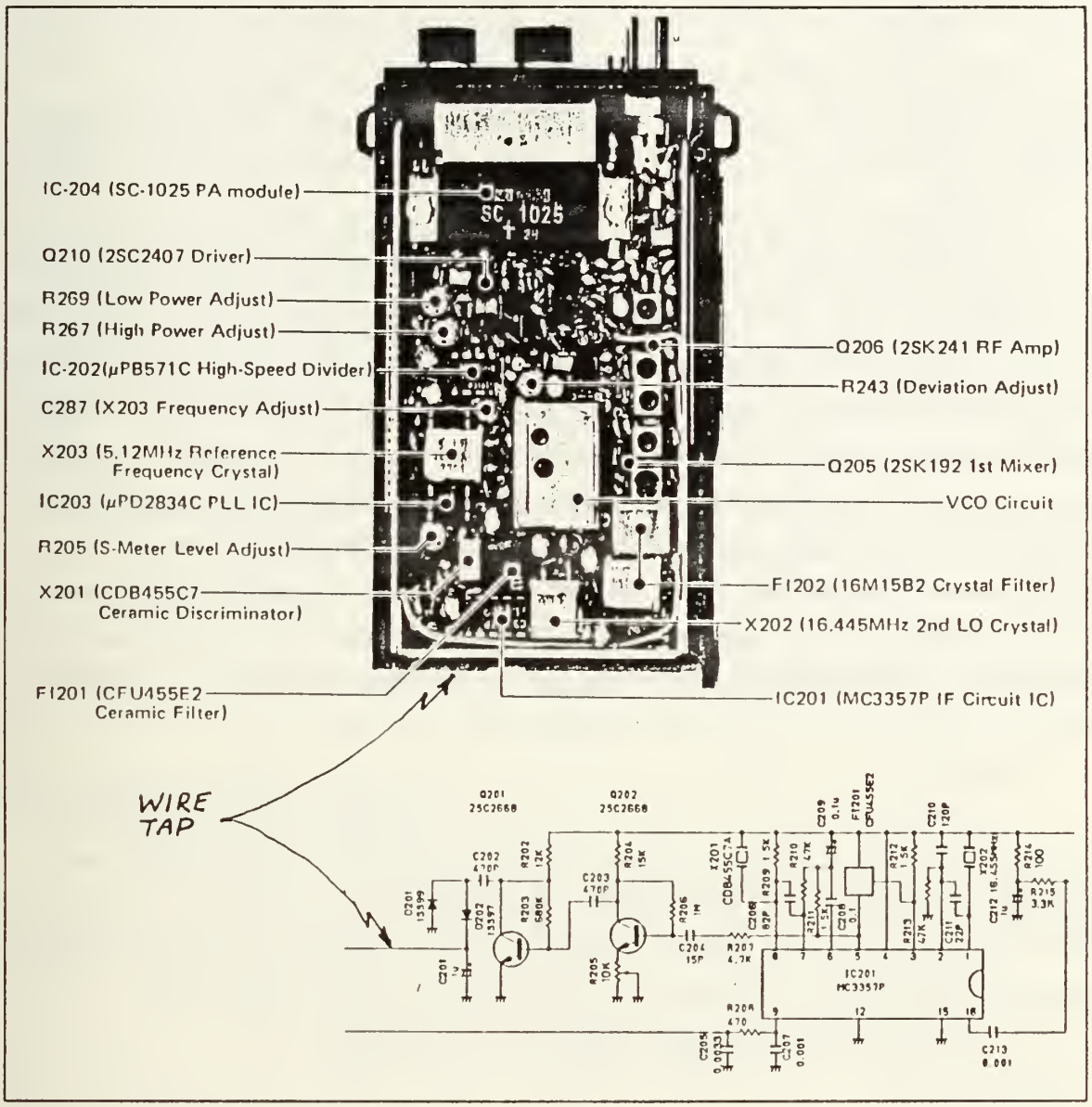


Figure 12. **SNR Wire Tap:** Wire tap point is illustrated and can be located by removing the back cover of the ICOM and tapping into the wire, which runs across the bottom. The schematic only shows the circuit section of interest.

available for connection between the computer and the TNC (9600 baud used), and one baud rate between the TNC and the transceiver (1200 baud).

Several modifications are made to replace connectors with soldered connections to minimize malfunctions during deployment. Additional connections (*connect status*, pin 1 on the DB-9 connector and *unacknowledged packets pending status*, pin 8 on modem disconnect header J5) are routed from the TNC to the TT4 for automation management of the telemetry sequence (see Figure 10 for protection circuits between TNC and TT4).

Instructions exist for each brand of TNC for setting the incoming audio level, outgoing deviation level, baud rates and the extensive protocol command list. The system flexibility resides in the command list structure and does require familiarization to take full advantage of the capabilities. Default settings are preselected to provide for the most general applications. Settings differ for each mooring and shore station. The flexibility of the packet protocol lies in the extensive command structure. To gain maximum data throughput requires familiarization with the proper selection of the protocol commands. The command settings are input to the TNC on the 9600 baud computer connection using the PC-TALK III software program. A battery back-up in the TNC keeps the command settings in memory after power is removed. The recommended changes to the TNC protocol default settings are listed in Appendix K. Hardware mounting configuration is illuatrated in Appendix G.

4. Antenna

The telemetry antenna used is an unbalanced hybrid dipole (transmission line is an unbalanced coaxial cable vice a balanced parallel feed line). The unbalanced antenna results in a slight degradation (0.3-0.5 db) in performance over the balanced antenna, but the unbalanced system is desirable because it provides a significant improvement in structural reliability over the balanced antenna feed point system. (Shaw, 1973)

The unbalanced hybrid dipole has the following features:

- Rugged design
- No balancing networks
- Coaxial cable feed (unbalanced 50 ohm)
- Low angle of radiation
- Constant impedance
- Ground plane independent (antenna currents balanced without a ground plane structure).

This antenna is not commercially available and requires internal manufacturing using the specification in Figure 13. During the project testing period, a less rugged

unbalanced hybrid dipole design was used. The final antenna will be made from stainless steel and tuned for the newly pending frequency assignment of 143.675 MHz.

Antenna height factor calculations are used to determine system performance. Usually system performance improves by increasing the antennas height above ground, except over the ocean. The ocean is an excellent radio frequency (RF) reflector, where as, the ground (soil) acts as an RF attenuator. The result is that antenna gain is degraded between one and four wave lengths above the ocean surface before any height gain occurs. This is because the RF reflection off of the ocean results in indirect and direct RF interference to cancel the gain near the surface of the ocean (Figure 14) As a result, an antenna placed at one wave length (2.08 m) has as much gain as an antenna at four wave lengths (8.32 m), and wave lengths anywhere in between only cause loss of performance. Consequently the antenna height will be 2 m above the ocean.

The vertical radiation pattern of a motionless vertical, unbalanced hybrid dipole is shown is Figure 15. The parasitic element (stub) on the antenna cancels undesirable radiation, which maintains the impedance of the antenna (Shaw, 1973). This minimizes the influence of the ocean acting as a ground plane, thus reducing antenna pattern distortion during tilting by wave and wind action.

B. SHORE SYSTEM PACKAGE

1. Automated data collection

The automated data collection for the shore station is block outlined in Figure 8. At the Point Sur, CA, shore station, the transceiver, TNC and PC-XT type computer will be continuously monitoring for the packet transmissions from the moorings (or the system can be further automated for turn-on near the time for mooring transmissions). The computer can be any RS232 compatible system. For a PC-XT system, a versatile communications software program is DIGIPAC I, by Kalt and Associates of Anchorage, AL. Other programs such as PC-TALK III can be used, but for actual packet telemetry, which can support multiple system telemetry connections, a program specifically designed for packet TNC communications, such as DIGIPAC, is recommended.

This is a hands off system, which can be as simple as collecting the computer printouts, or as complicated as an automatic phone modem connection to relay data to a remote computer. Figure 16 illustrates one type of computer setup used for testing between Point Sur, CA. and the research vessel Point Sur.

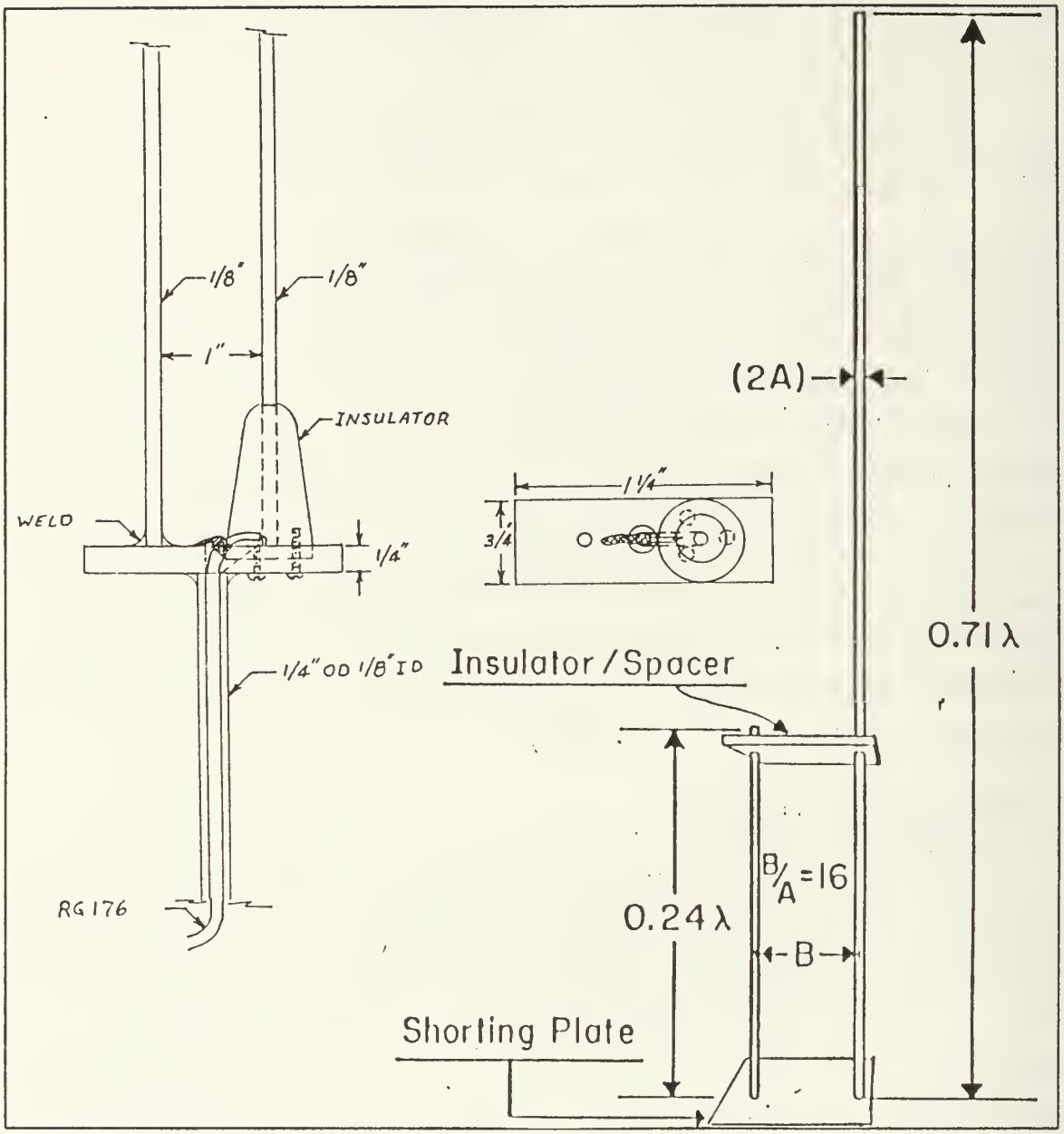


Figure 13. Construction Details for the Unbalanced Hybrid Dipole: The hybrid dipole design is from Shaw, (1973). It was designed to perform in marine and mobile applications without the requirement for a ground plane. For 143.675 MHZ, $\lambda = 2.08$ meters. Constructed of stainless steel, with plastic insulators. Silicon sealant fills all voids to protect the exposed sections of the RG 176 coaxial cable.

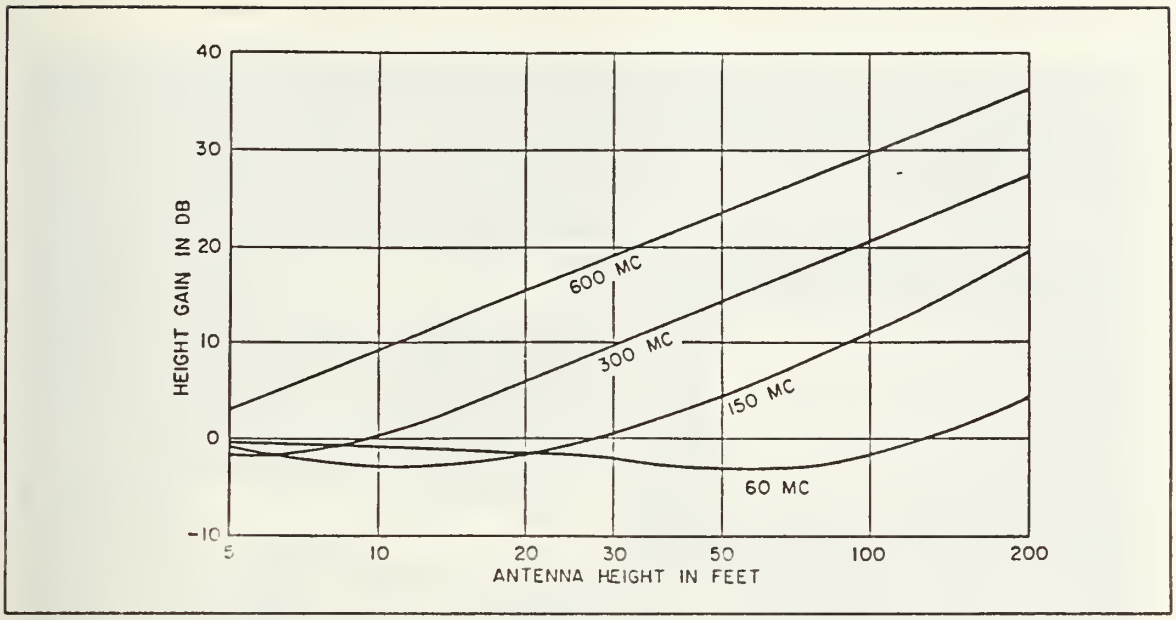


Figure 14. Antenna height gain differences over the ocean (Jasik, 1961): Antenna height gain differs over the ocean. The wave length for 150 MHz is 2 m. Note that between one wave length and four wave lengths there is a loss in gain. This project will use 2 m for antenna height.

2. VHF NBFM transceiver

The transceiver used for the shore station is an unmodified ICOM 28A. This unit can be tuned between 140-150 MHz, has 5 and 25 watt power output selections (25 watt selected) and operates on 12 volts DC. Selection was based on its frequency coverage, cost and prior approval for use by the Navy on military frequencies.

Three connections required are: 12 volt DC, antenna, and the transceiver to TNC cable. The construction details for the cable are generally included with the TNC instruction manual.

3. Packet TNC

The packet TNC is a Pac-Comm model TNC-220. This unit operates on 12 volts DC, connects to the computer's RS232 via a DB-25 connector and has two radio ports for the flexibility of operating on two different frequencies (if given two frequencies to operate on). There are no modifications required. Connection procedures and system adjustments are fully illustrated in the instruction manual.

For telemetry, the default command settings are listed in the Appendix K. These command sets are set by the PC-XT using the DIGIPAC program.

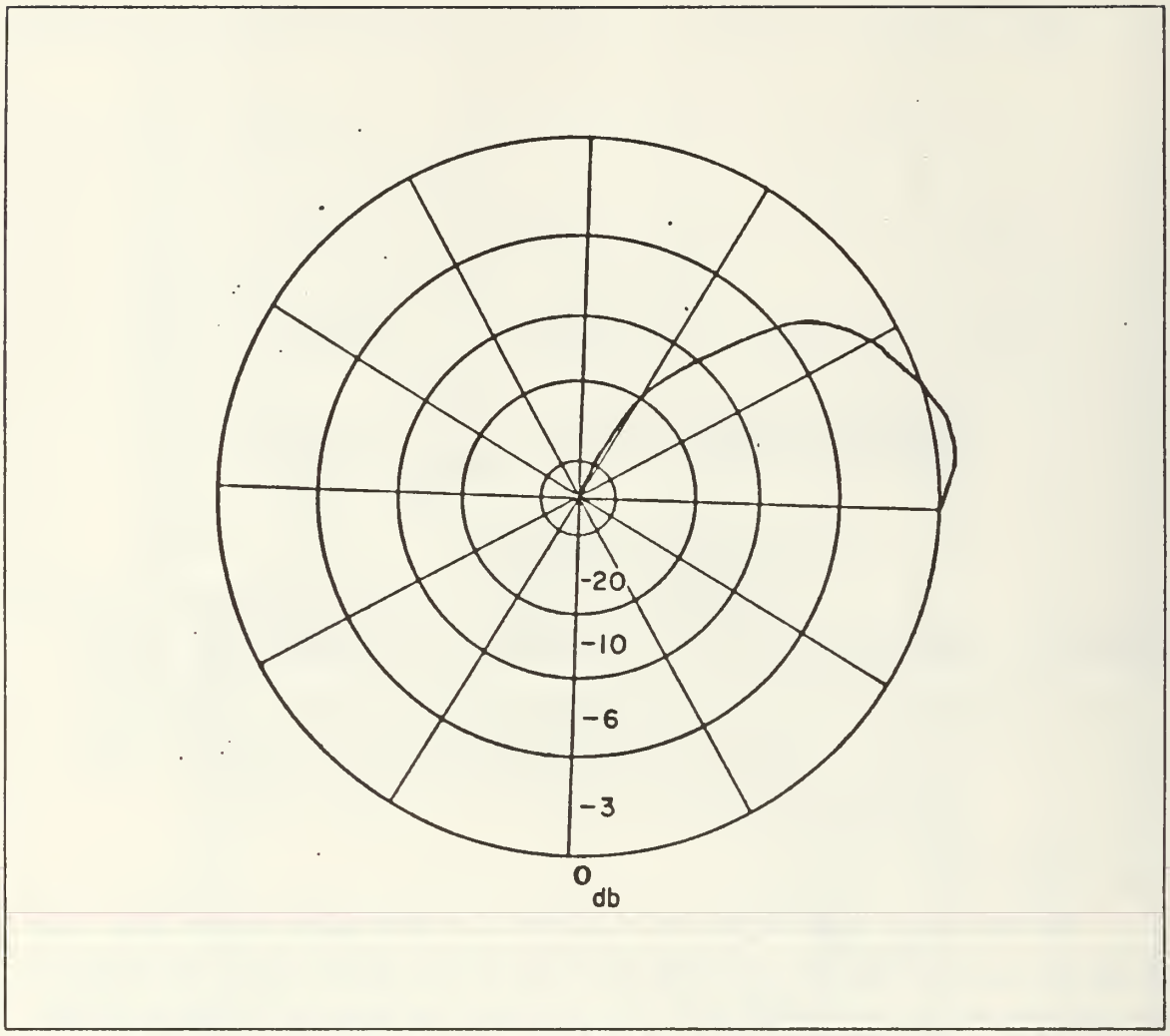


Figure 15. Elevation Radiation Pattern of the Unbalanced Hybrid Dipole (Shaw, 1973)

4. Antenna

The antenna used for the shore station is a high gain, narrow beam, vertically polarized antenna by Cushcraft Corporation of Manchester, NH, model 230 WB Boomer (Figure 17). Specifications for the antenna are listed in the Appendix J. This antenna directs its pattern in a narrow horizontal beam down the line-of-sight of the moorings to be monitored off the Point Sur, CA, transect (Figure 5). The antenna is constructed of aluminum and stainless steel fasteners and has a total weight of 22 pounds. The antenna is subject to salt water corrosion, but considering its cost ($260),

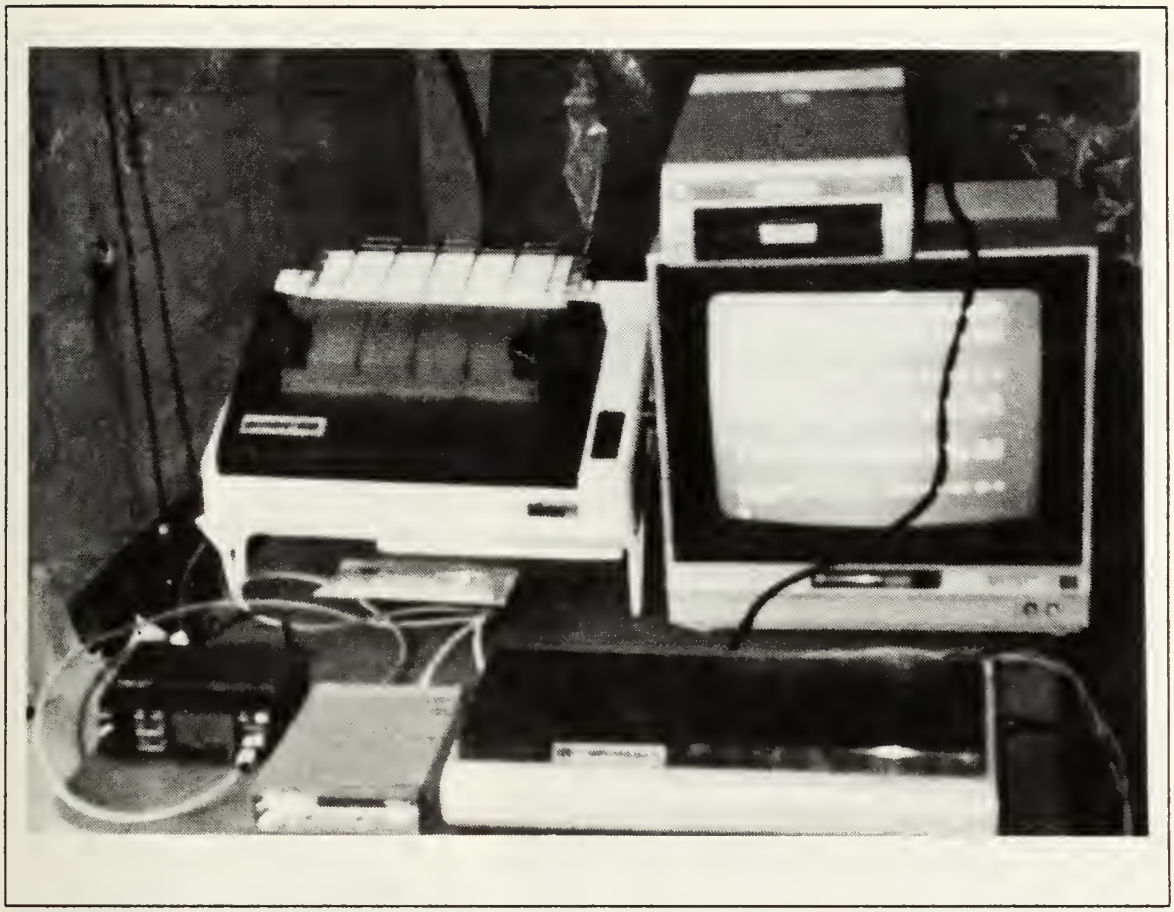


Figure 16. Initial Telemetry Experiment Between Point Sur, CA, and Research Vessel Point Sur: The initial telemetry test used an ICOM 28A, Pac-Comm TNC 220 and a Commodore computer system.

it can be replaced annually or for each mooring cycle. Regular antenna replacement will ensure maximum performance.

At Point Sur, the Coast Guard must authorize any installations on the tower. The park ranger at Pfeiffer Big Sur State Park, Big Sur, CA, should also be contacted to ensure that the proposed antenna structure is not offensive in appearance. The tower is illustrated in Figure 18. Preliminary inquiries indicated that both the Coast Guard and the Park Service will support this project.

5. Site selection

Point Sur, CA, was selected as the site for the shore station, because it is nearly in line to the mooring transect seen in Figure 5. During the two testing periods, access

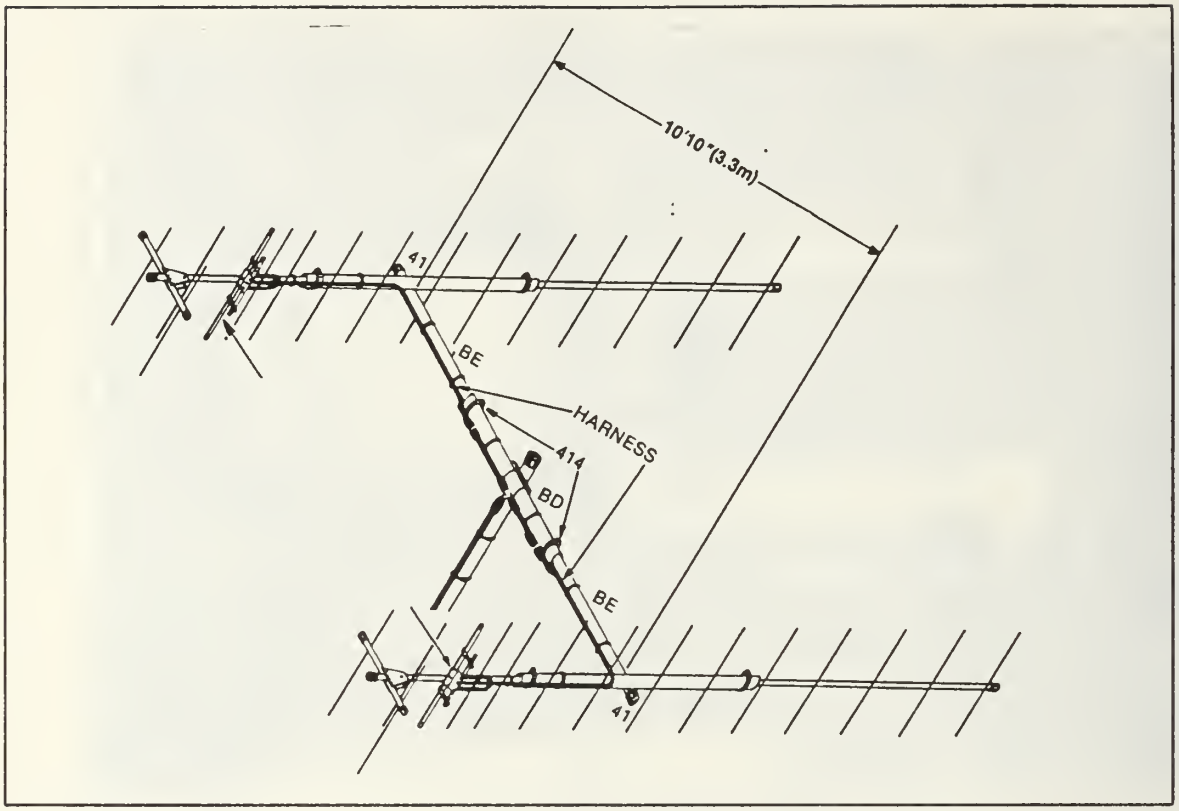


Figure 17. Shore Station Antenna: The antenna is a high gain, vertically polarized antenna. It is a light weight, low cost, aluminum structure. Salt air corrosion will require annual replacement in order to insure maximum performance. Specifications are listed in Appendix L.

was gained to Point Sur, from the Pfeiffer Big Sur park service. Liaison was established with the head ranger, (Tex Ritter) and the Coast Guard, Monterey, CA, to secure site usage on the tower. Site usage is highly probable for a future installation, but must first be cleared with the Coast Guard Engineering Section in Alameda, CA. Clearance requires forwarding the telemetry system specifications indicating type of antenna, antenna gain, antenna beam heading, proposed position on the tower, transceiver power and frequency, to the Coast Guard via the park ranger. The assignment of an operating frequency has taken eight months and has been the longest lead time requirement for this project.

This site should provide satisfactory operation out to point P3 in Figure 5. If, for some reason, this site is unsatisfactory, the foot hills behind Point Sur could poten-

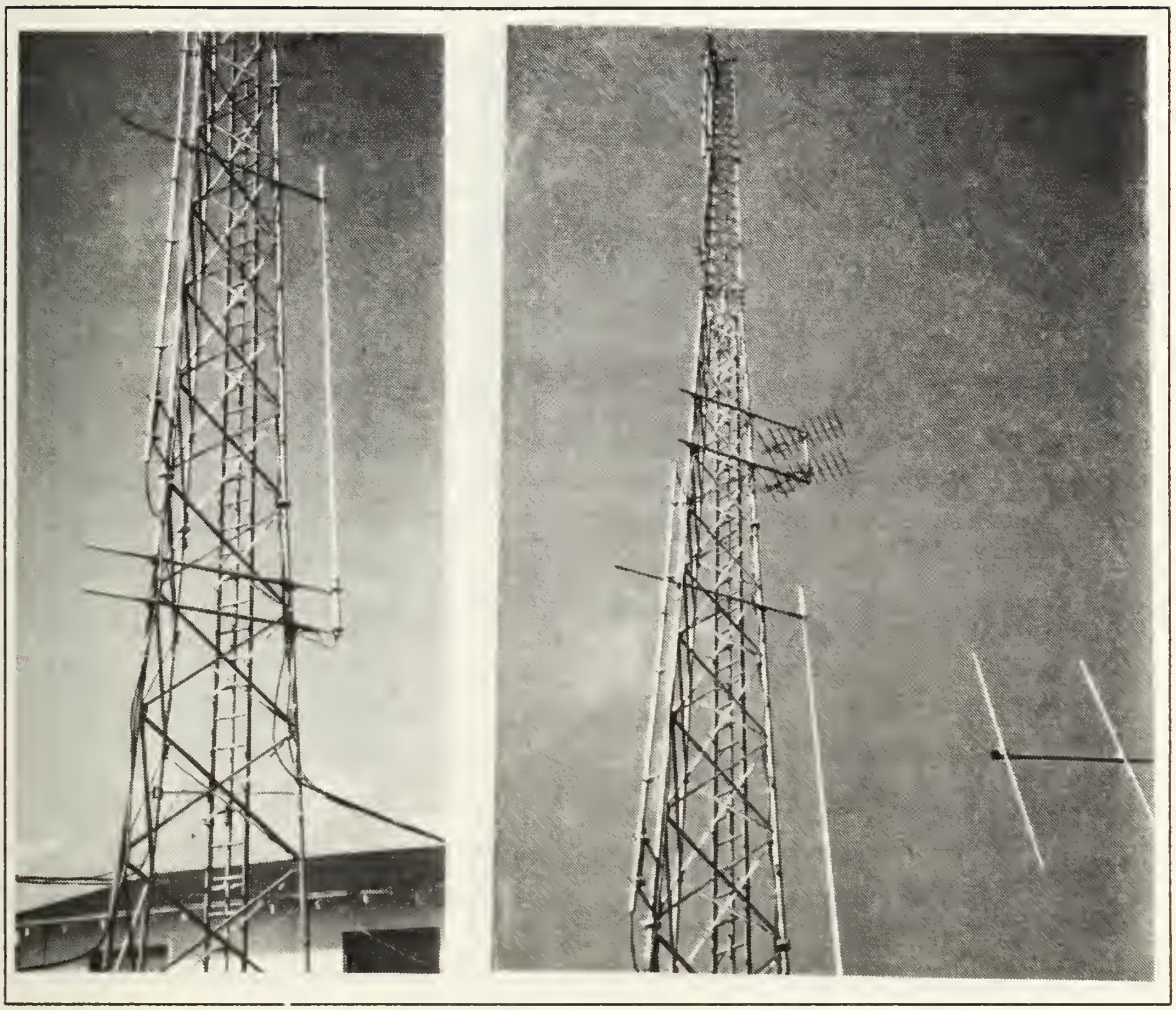


Figure 18. Point Sur, CA, Tower: This is a two section photo of the Point Sur tower. Final clearances through the Coast Guard and the Park Service are required to complete the antenna installation. Installation point is near the small pair of yagi antennas.

tially be used. This site is at 1200 ft on Little River Hill (Figure 19), which is much higher and therefore provides a better line-of-sight distance to the moorings. Figure 14 shows the free path loss maximum range between two antennas, which illustrates the difference between Point Sur at an elevation of 380 ft and Little River Hill at 1200 ft (this is also related to Figure 7). Environmental conditions, such as boundary layer influences and surface VHF trapping need to be evaluated before full consideration can be given to Little River Hill site.

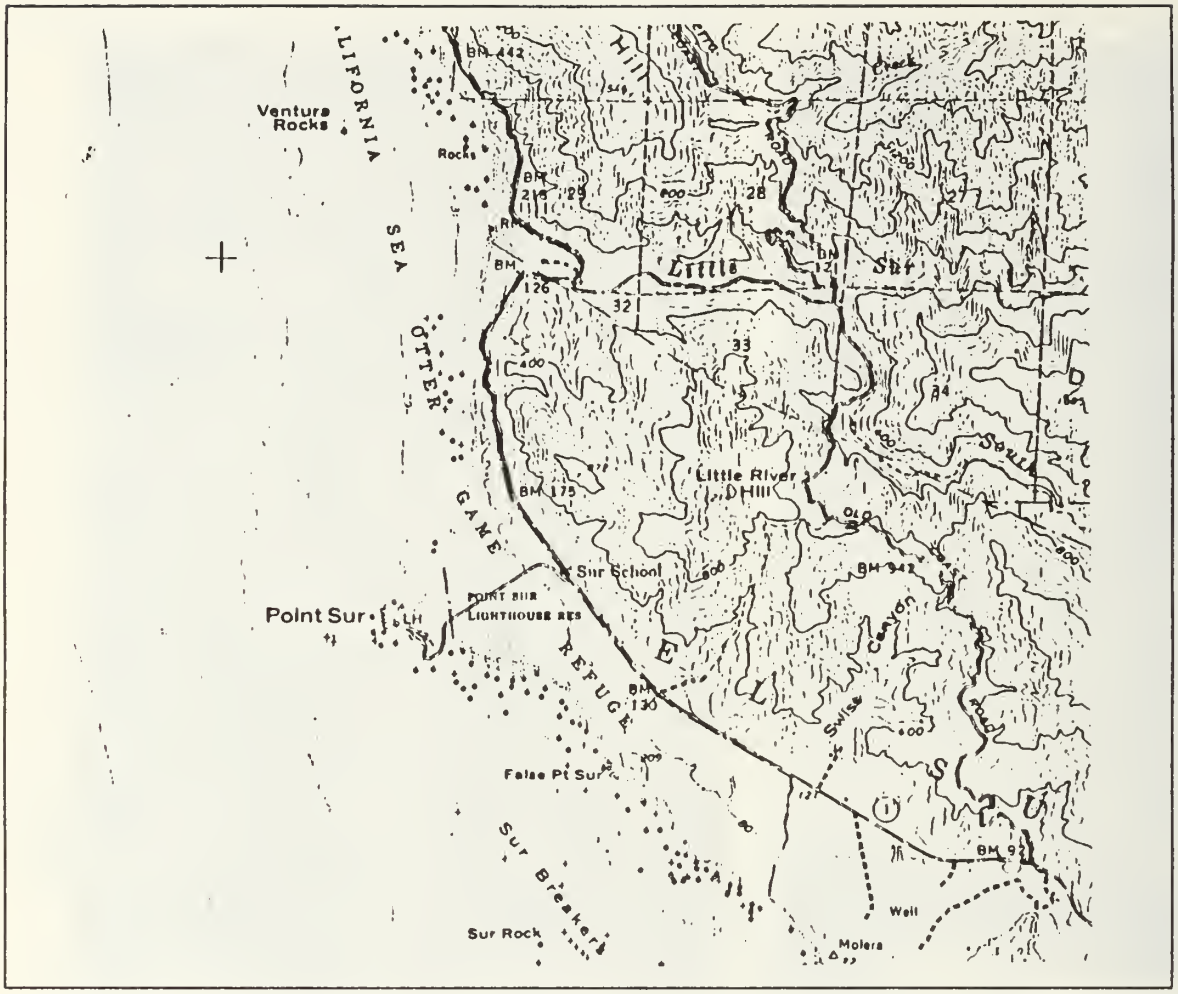


Figure 19. Topographic Map of Point Sur and Little River Hill: The Monterey County communications site on Little River Hill is a possible shore station back-up site for monitoring the mooring transect.

III. ENVIRONMENTAL CONSIDERATIONS

A. METEOROLOGICAL CONSIDERATIONS

1. Electromagnetic propagation

Telemetry operations in the VHF spectrum are subject to three conditions which control the range of a propagated signal: 1) boundary layer gradients, 2) trapping and 3) line-of-sight. Line-of-sight is the commonly selected propagation mode between two antennas in the VHF spectrum and is the mode this project will use. The other two modes are atmospherically controlled, but can affect line-of-sight propagation by creating multipath conditions resulting from boundary layer refraction interference and can potentially hamper FM reception. The marine boundary layer can also effectively extend the radio horizon by providing conditions of super refraction (trapping). Atmospheric inversions and passages of frontal weather systems provide unusually long range propagation via trapping.

a. Line-of-sight

The most reliable VHF propagation is line-of-sight via the free space transmission path. Only cases of sub-refraction, at the edges of the free space transmission path, will reduce propagation conditions. Atmospheric index of refraction (N) is a function of absolute temperature (T), pressure (P in mb) and moisture content (e) and is expressed in the form:

$$N = 77.6(P/T) + 3.73 \times 10^5(e/T^2)$$

The vertical gradient of N is (in terms of q instead of e where $q = 0.622e$ in gm/kg and is the water vapor mixing ratio):

$$dN/dh = c_1(dP/dh) + c_2(dq/dh) + c_3(dT/dh)$$
$$c_1 \cong 0.3$$
$$c_2 \cong 7.2$$
$$c_3 \cong -1.3$$

The classification scheme developed for the Navys' Integrated Refractive Effects Prediction System (IREPS) classification defines four refraction conditions using dN/dh:

- *Sub-refraction* dN/dh > 0 per km (reduced propagation)

- *Normal* (standard atmosphere) dN/dh = 0 to -79 per km (normal propagation)
- *Super refraction* dN/dh = -79 to -157 per km (increased propagation)
- *Trapping* dN/dh < -157 per km (greatly increased propagation)

Figure 20 illustrates the IREPS classification.

b. Boundary layer

The marine boundary layer has a large moisture flux at the surface which generally decreases with height, resulting in larger *q* gradients near the surface and smaller temperature gradients. The reduced mixing in the boundry layer causes larger gradients. The moisture flux from the ocean to the atmosphere is essentially confined to the thickness of the atmospheric boundary layer, which may range from a few hundred meters to several thousand meters. Refractive conditions exist where the q gradients are large at the surface and decreasing with height. Weather anomalies cause changes to the refraction conditions. Cold, dry, continental air moving offshore over a warm ocean produces the most intense evaporative moisture fluxes. When this situation is accompanied by a stable boundary layer, the vertical turbulent mixing is suppressed, which favors trapping of propagating electomagnetic waves. Warm moist air flowing over cold water can provide favorable propagation if fog is produced in the surface boundary layer. In such cases, the lower atmosphere is completely saturated, while the air above may be considerably dryer, resulting in sharp gradients of q and potentially strong refraction. (Brooks, 1984)

The marine boundary layer conditions off of Point Sur, CA, seldom supports a sub-refraction condition. However, a long term study is needed to investigate the influence of multipath refraction conditions when trapping conditions exist. Line-of-sight communications can be expected under all other conditions. The height of the antenna on Point Sur (380 ft), will usually be in the marine boundary layer, but the alternate shore station site at Little River Hill with an elevation of 1200 ft, may be subject to cross boundary propagation conditions. A decision to use Little River Hill will require investigation into the potential propagation limitations, i.e. Little River Hill may not receive the buoy signal under strong surface ducting conditions.

c. Trapping

Trapping (or ducting) conditions exist when the dN/dh < -157 per km and this layer is thick enough to trap the frequency of interest. This condition occasionally occurs for the 140-150 MHz frequency at Point Sur, when a frontal passage develops a trapping layer gradient condition (dN/dh < -157) over a vertical distance greater than

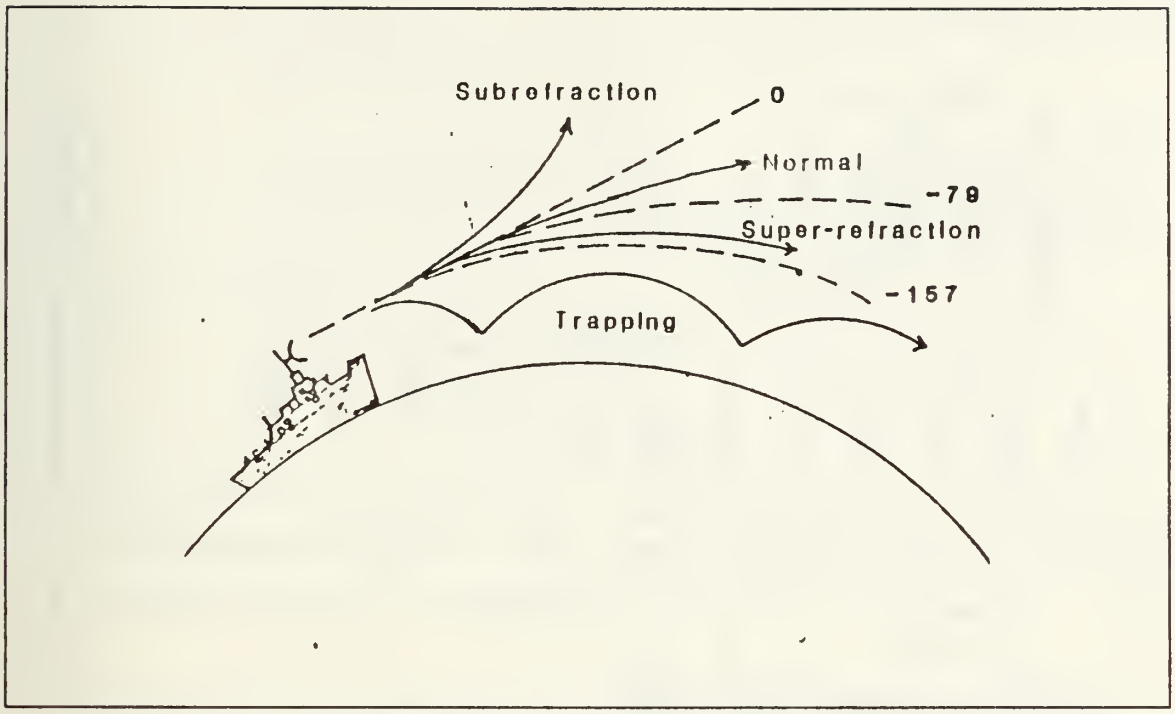


Figure 20. IREPS Classification of EM propagation: Propagation of RF in the VHF spectrum is influenced by boundary layer gradients, which change the refractive index and influence propagation.

185 m. While it can significantly enhance SNR, it may also permit long range propagation of interference to actually reduce the SNR. Timing of telemetry in the morning (when the sea and air temperatures are closer together than in the afternoon) will minimize the condition favorable for trapping development. Figure 21 from Miller (1986), illustrates ducting vs frequency and refraction index classifications.

2. The effect of wind stress on the buoy antenna pattern

The telemetry system will transmit once per day, preferably under calm conditions. Coastal winds were studied for diurnal variability at Moss Landing, CA and Monterey, CA, using 30 minute averaged data recorded for the year 1988. The data came from monthly reports issued by Monterey Bay Aquarium and Moss Landing Marine Laboratories Monthly Weather and Oceanographic Summary. The weekly plots of the 30 minute averaged values of air temperature, solar irradiance, wind direction, wind speed and barometric pressure are shown in Figure 22. By over-laying eight weeks of plots, the diurnal variations became evident. This over-laying technique was applied

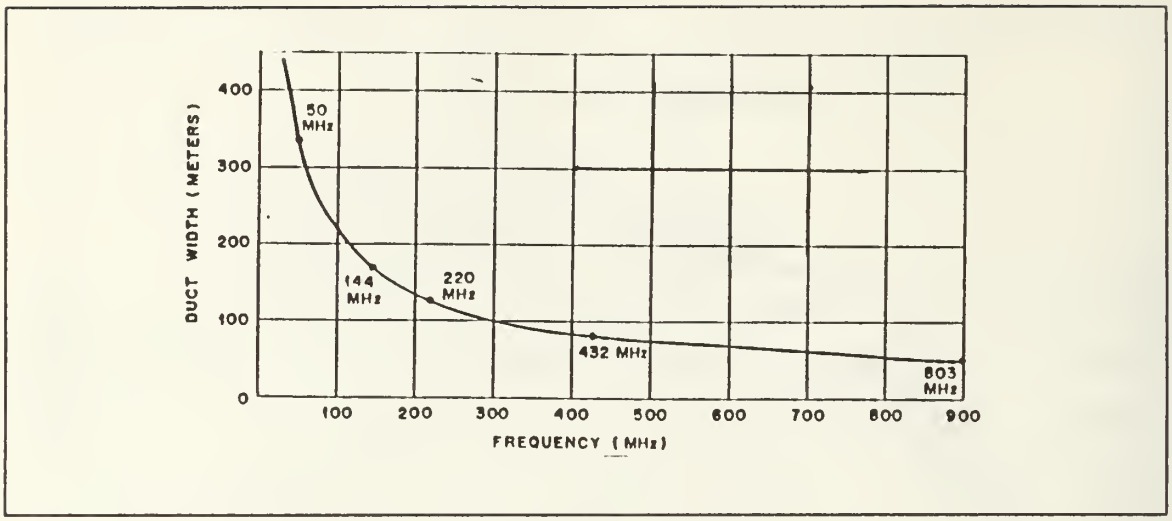


Figure 21. Trapping vs Frequency (Miller, 1986): This graph illustrates the relationship of the trapping layer thickness to the frequency which can be trapped.

for each season in 1988, and a diurnal pattern for coastal meteorology became clear and is characterized in Figure 22. What is seen is that the nearshore wind (and other parameters) had a typical and predictable pattern (Figure 23) indicating winds are a minimum at sunrise and maximum in the late afternoon. This same observation was noted by Beardsley *et al*, (1987) in his description of the marine boundary layer and atmospheric conditions over a Northern California upwelling region. His study depicts the same diurnal wind speed, wind direction and time of maximums and minimums. Beardsley (1987) showed that this diurnal affect was a coastal phenomenon, and the diurnal influence becomes very weak at about 35 km out to sea.

These studies indicate a wind speed minimum near sunrise out to about 10 miles offshore, which should provide the optimum conditions for data telemetry. For a mooring transect, such as at Point Sur, the near shore telemetry system would be timed to transmit at sunrise. The more seaward telemetry systems can also be programmed to transmit at sunset or at any other time of the day.

B. OCEANOGRAPHIC CONSIDERATIONS

1. Wave height effects on buoy antenna pattern

The way in which ocean motion influences a floating vertical antenna are very difficult to predict. Buoy motion is a result of wind and wave action on the antenna and

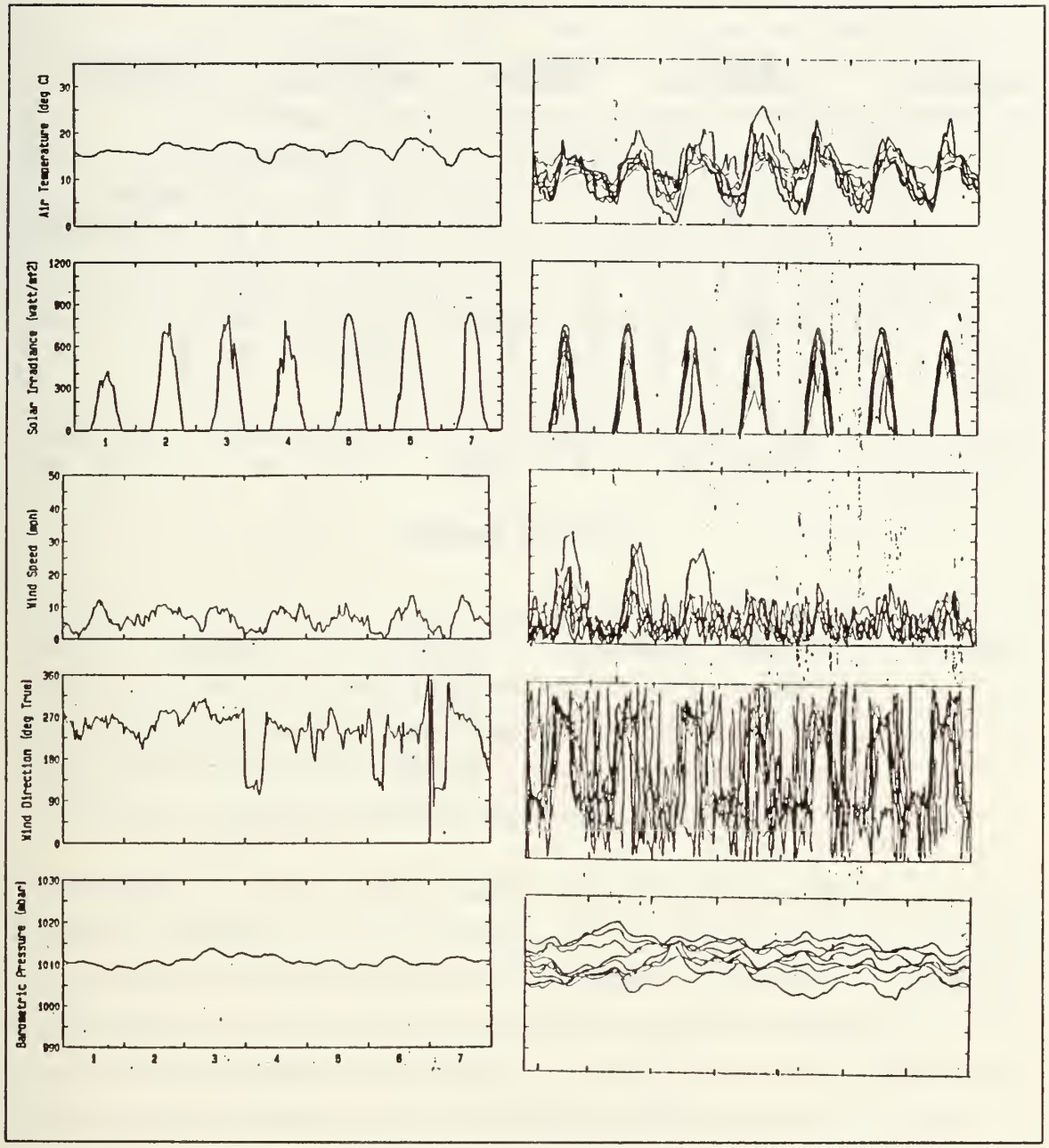


Figure 22. Monterey Coastal Meteorology Monthly Weather Summary Plots: The plot on the left is a sample of a week of the year from the Monterey Bay Aquarium and Moss Landing Marine La'boratories Monthly Weather and Oceanographic Summary and on the right is an eight week overlay.

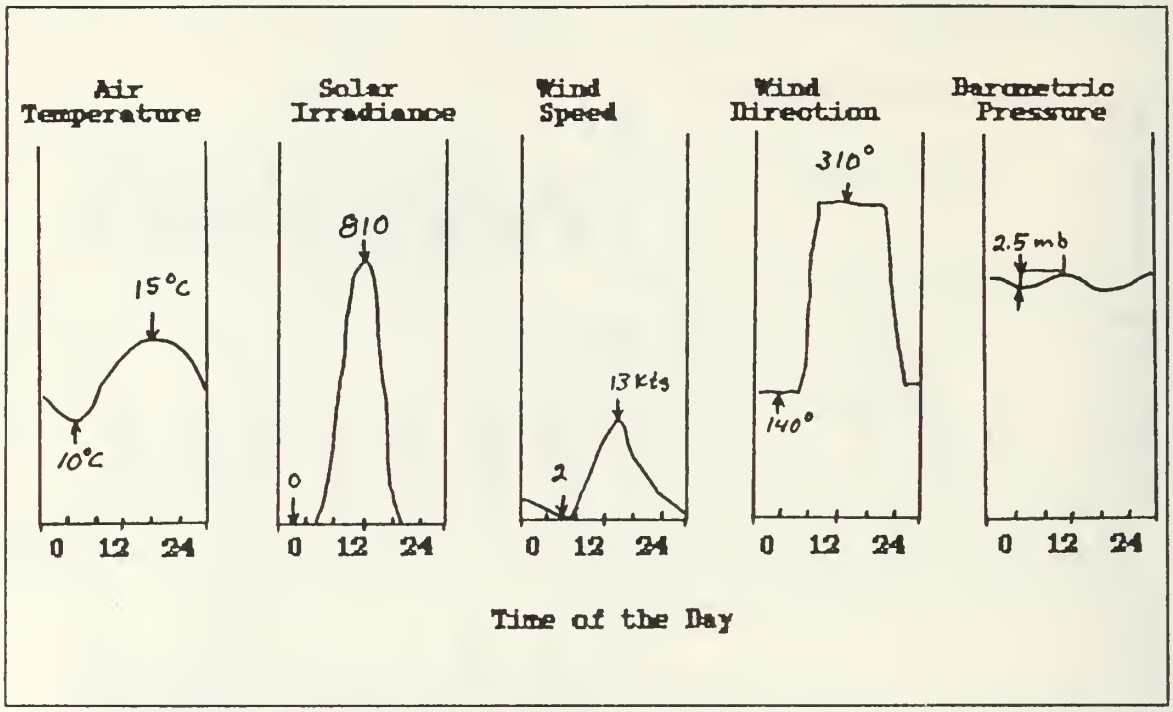


Figure 23. Typical Characteristic Curves of Monterey Coastal Meteorology: Curves were developed from the characteristic plots such as seen in Figure 22. These diurnal patterns where found to be repetitive though out the year. The same similarity of the time scale, wind speed and wind direction can be found in Bearsdsley et al., 1987.

the local wave field can influence the interference pattern of direct and indirect RF propagation paths. Figure 15 shows the radiation pattern of the proposed unbalanced hybrid dipole. The parasitic stub influences current distribution on the antenna (Shaw, 1973), but this particular design has not been tested over the ocean to see what influence the ground plane of the ocean will have on a tilting antenna. Results of a static tilt test, done between a shore station and a beach 52 km away, are discussed in the next chapter. The tests verify that the hybrid dipole antenna can perform under tilting conditions similar to those that may be experienced by wave and wind influences.

C. SURVIVABILITY OF SURFACE BUOYS

1. Environment, shipping lanes and fishermen

Experience with long-term survivability of moored buoys is not good (Briscoe et al., 1985). A review of Figure 6 and the transect mooring site of Figure 5 indicates

that over a 180 day deployment, the survivability of a surface buoy can be questioned just based on the shipping density alone. Fishermen also present hazards, but their hazards apply to both surface and submerged moorings. The main concern is the chance netting of a fixed mooring. At least with surface buoys the fishermen avoid netting the mooring. Submerged moorings, however, are still subject to damage. For either case a *Notice to Mariners* is required, both to address the safety issues for the fishermen and the survivablity of the moorings. The pop-up buoy design is a popular concept that has not been successfully deployed, but if deployed it will avoid the surface shipping traffic and hazards of the surface environment. It will not alleviate the fishermen problem.

IV. SYSTEM INTEGRATION AND TESTING

A. BUOY MOUNTED EQUIPMENT

1. Electromagnetic compatibility (EMC)

a. Computer to radio EMC

Electromagnetic compatibility ensures that the electromagnetic radiation caused by oscillators, pulsing circuits and system non-linearity are isolated from other equipment. The most graphic example is radiation from the computer clock which is a 4 MHz square wave signal. To reproduce the 4 MHz square wave requires a broad spectrum of Fourier harmonics, but if the 4 MHz clock produced a sine wave, only the 4 MHz frequency would be present.

As the proposed system consists of integrations of other equipment designs, interference requiring correction can occur. The standard EMC discipline procedures to correct problems are:

- Shielding (fully enclose equipment in metal containers)
- Filtering (provide a low impedance to ground to offending radiation)
- Physical Separation (relocate equipment and enclosures)
- Circuit Design (component arrangement for minimum interaction)
- Frequency Assignment (do not operate on related harmonics)
- Avoid common signal and power grounds (power flow noise interference)

These EMC disciplines have limitations:

- Practical filter limitations
- Space limitations
- Design trade-offs
- Available frequency

If poor EMC exists after prudent procedures are used, then a measurement methodology is required to obtain a spectrum signature.

Initial system integration of the TT4, TNC and ICOM indicated that the TT4 and the TNC generated noise which was reduced by putting the ICOM in a separate enclosure. Improvement in the ICOM's sensitivity was obtained using a preamplifier between the ICOM and the antenna. System design limitations required the preamplifier to be mounted with the ICOM and not at the antenna. The ICOM's per-

formance was definitely improved, but when operated with the TT4 and TNC, the performance margin disappeared.

b. Methods to overcome EMC

Poor EMC problems existed and are eliminated by enclosing the TNC and TT4 in one enclosure and the ICOM and preamplifier in another enclosure. Figure 24 illustrates the two enclosures, with the larger enclosure containing the TNC and TT4. On both enclosures, all electrical connections (except the antenna) were passed through feed-through terminals. Each terminal is fitted with very short lead capacitors rated at .05 μf to short any 4.9152 MHz oscillator signals from both the TNC and TT4 microprocessor oscillators and a 100 pf to short to ground any 143.675 MHz harmonics. Figure 25 illustrates the point that capacitors used at one frequency can behave quite differently at higher frequencies. Theoretically, the .05 μf should short all signals from 5 MHz on up, but at 143 MHz the leads to the capacitor develop inductive reactance and remove the low impedance to ground. The 100 pf capacitor restores the low impedance to ground for 143.675 MHz harmonics. Additional shielding precautions where taken to isolate noise sources by securing the enclosure lids with sheet metal screws every 3/4 inches and to cover all holes with copper adhesive tape. The end result is negligible computer noise in the ICOM, thus improving the ability to gain a margin of signal excess.

2. Power distribution

a. Battery systems and capacities

The battery systems are a critical element in determining the size, weight, and power handling limitations of each subsystem. The project has three subsystems requiring battery power:

- TT4 and Aanderaa hydrophone
- Telemetry transceiver
- Underwater winch

The TT4 and hydrophone subsystem requires continious battery power for the duration of the system deployment. The current drain is averaged to 5 MA for the TT4 and 3 MA for the hydrophone. On the conservative side, this subsystem requires 10 MA continuous current, which equates to 43 Amp Hours (AH) for a 6 month deployment. the TT4 voltage requirement is any value between 7 and 15 volts and the hydrophone voltage requirement is any value between 6 and 9 volts. Each system has

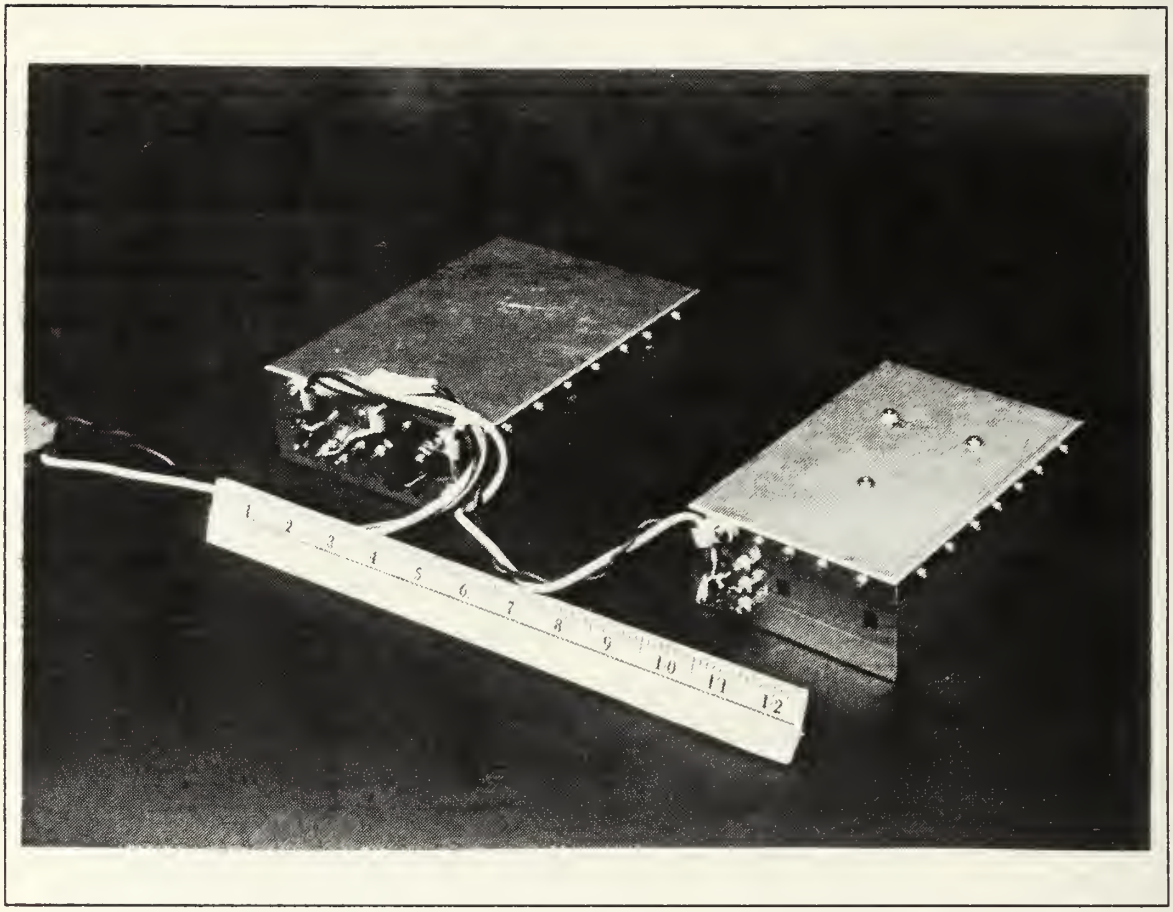


Figure 24. EMC Protection Using Shield Materials: To ensure EMC, the TNC and TT4 are enclosed together in the larger container, and the ICOM and preamplifier are enclosed in the smaller container. Each electrical connection is filtered to remove noise, all holes are are sealed and the container lids are secured with sheet metal screws every 3/4 inch.

an internal voltage regulator, which permits battery voltage variations without affecting system operation.

The telemetry transceiver subsystem has a power surging demand for less than 5 minutes per day for the deployment period. The current drain is maximum of 1.3 amps for transmit and 100 MA for receive. On the conservative side, this subsystem requires 15 hours of power over a 6 month deployment, which equates to less than 20 AH of power. The power output of the transmitter section of the telemetry system is very sensitive to changes to the battery voltage. The higher the battery voltage during

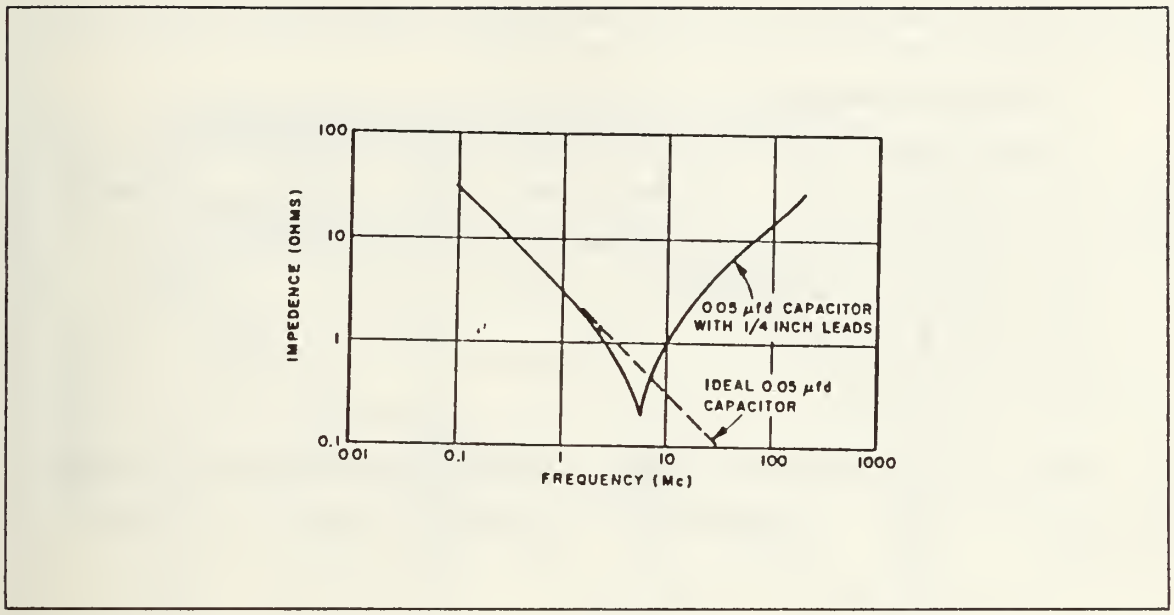


Figure 25. High frequency performance of a typical capacitor: A .05 μf capacitor has a low impedance at 5 MHz and higher, which makes it ideal for grounding out all electronic noise from 5 MHz and above if there is no inductance in the capacitors leads. However, capacitor leads do have inductances and associated inductance reactance causing increased impedance with frequency. The feed-through connectors have two capacitors connected to ground, one to ground 5 MHz and the other to ground 143 MHz noises.

transmission, the greater the power output of the transmitter. The telemetry system requirement is a constant voltage battery source, which does not vary under transmitting load conditions.

The underwater winch subsystem requires large power consumption once a day, during buoy recovery. Buoy buoyancy should be sufficient for surfacing and should not require any power consumption. This area is the least researched. High torque, low current (4 amp) and higher voltage (48 volt) DC motors are available. Such motors are used in high speed computer tape drives. Preliminary experimentation with such a motor revealed that very large surge currents are required to establish the initial magnetic starting fields, but much lower currents were required to maintain the high torque requirements. It was found that this subsystem was found easy to start using a bank of 50,000 μf capacitors, which are electrically floated on the battery supply. In starting the

motor. the bank of capacitors provided the needed surge current which reduced the demand on the battery system, thus extending battery life.

b. Battery characteristics

The batteries selected are required to function at 5 degrees C, have a long shelf life, operate in any position and have minimum gasing on discharge. These requirements can be met by three types of batteries:

- Alkaline-Manganese Dioxide (AMD)
- Lithium-Sulfur-Dioxide (LSD)
- Sealed Lead-Acid (SLA)

Each of these batteries have limitations which would eliminate exclusive selection for all three subsystems. Table 3 on page 51 shows the physical parameters of the three types of batteries.

Table 3. **PHYSICAL PARAMETERS OF THE SELECTED PROJECT BATTERIES.:** Batteries were combined to equate to a single 20 AH source to provide comparison of cost, weight and size for equivalent battery capacities.

Battery Type	AMD	LSD	SLA
Brand Name	Duracell PC926	SDX(G20 12) Eternacell	Power Sonic PS-12200
Voltage range	12 to 6.4	14	12.3 to 11.8
20 AH weight	61 oz	42 oz	282 oz
20 AH size	72 ci	49 ci	220 ci
Cost (est)	$14	$100	$70

Figure 26 illustrates the discharge characteristics for each type of battery.

The AMD can handle the low current-drain subsystem (TT4 and hydrophone), which is able to operate under varying voltage levels. The LSD can handle the constant voltage requirements of the telemetry system and has the added advantage of light weight and small size making it ideal for the pop-up buoy. But these batteries are expensive and require special handling to prevent explosions which result from methane gas production when operated at excessively high discharge rates. The SLA

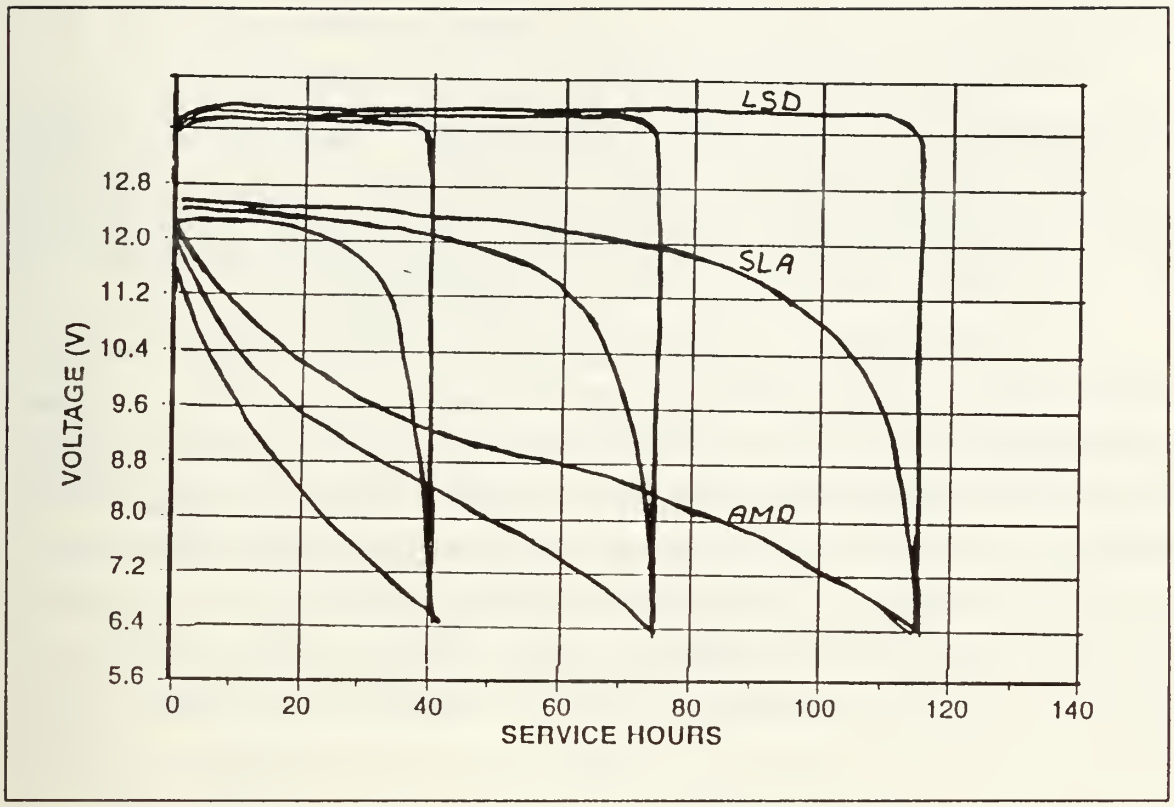


Figure 26. Discharge characteristics of the selected project batteries:: The AMD has a large voltage drop under moderate battery loading. The LSD maintains a constant load voltage until discharged. The SLA has a slight load voltage drop during battery life.

can handle the high current requirements of the winch subsystem, provided that sufficient buoyancy is available to support the batteries. The winch subsystem battery demand has not been calculated, but it is expected to be at least 100 AH. This would exclude the LSD due to cost and size of the potential explosive hazard.

Design intergration of a prototype system will require experimentation to consider the LSD for the TT4, hydrophone and telemetry subsystems.

3. Antenna

a. Vertical polarization and wave motion

There are two primary designs for antenna polarization: vertical and horizontal. Each design can be omnidirectional or directional. An omnidirectional-vertical polarized antenna has a pattern which functions uniformally around the horizon. A

directional-vertical antenna was not considered because the antenna requires streering to maintain an antenna pattern towards the shore station.

Horizontal omnidectional radiation patterns are developed using vertically polarized antennas which require vertical radiating elements. The omnidirectional gain of a vertical antenna is increased by selection of antenna height, the number of stacked antenna elements and the relative distane to a real or artifical ground plane (Figure 13, Figure 14 and Figure 15). The design used is illustrated in Figure 13.

A critical element in buoy antenna systems is the ability of the antenna to function while under the influences of wave motion and wind stresses. Antenna polarization between two stations should be the same, but as a result of wave motion and wind stresses, the polarization of the buoy antenna is constantly changing. When antennas are cross polarized (90 degrees off axis to each other) a gain reduction of as much as 20 db can occur. To compensate for the signal fluctuations, the antenna and buoy flotation structure must be designed to limit the effects of wave motion and wind stresses. The total system integration concept is to maximize data throughput using redundent error checking transmissions, signal excess to overcome antenna motion and buoy design to limit wave motion effects.

B. SHORE STATION

The shore station at Point Sur, CA, was selected because of its postion, elevation, access and availability of electrical power. Point Sur is on a line with the transect (Figure 5) and has a sea level elevation of 340 feet. Being on a line to the transect permits a vertically polarized directional antenna (Figure 17) to be used to intercept buoy transmissions, and with the elevation, the transmissions can achieve a range to just beyond 30 NM. The antenna tower at Point Sur (Figure 18) can provide an additional 40 to 60 feet of elevation to the antenna installation. No modifications are required for the packet telemetry shore station equipment. The installation in Figure 16 was not subject to ECM problems, but if equipment and computer types are mixed, some ECM may occur requiring repositioning of equipment. Interconnections of equipment are sufficiently detailed in the equipment documents. The antenna installation will require periodic checks for corriosion, structural alignment and electrical measurements of the voltage standing wave ratio (VSWR), because of the salt, fog and wind environment at Point Sur, CA.

C. TESTING

1. Buoy to Point Sur shore station

Two testing periods were conducted between the Point Sur, CA, and the R/V Point Sur. Each testing period involved the R/V Point Sur operating along the transect line (Figure 5). The first test involved determining which propagation path should be used. The second testing period (a few months later) involved an in-water test of the buoy package, using the best propagation path determined from the first test.

a. Testing propagation modes

This first at sea test was designed to find out which mode of propagation (direct or surface ducting) could achieve a 52 km telemetry path over the water. This test used three packet stations: 1) an automatic response to query buoy package on the R/V Point Sur (package physically attached to the ship with the antenna at 15 feet above sea level), 2) an automatic response to query beach mounted package at 10 feet above sea level, next to Point Sur, CA, and 3) the master query station (Figure 16) at 360 feet above sea level on Point Sur, CA. From the master query station several connection modes were possible for testing the ability of each station to connect to the other stations:

- master to buoy
- master to beach
- master to buoy via beach
- master to beach via buoy

Additionally, the buoy and beach stations where programmed to send 30 minute beacon transmissions as an additional monitor routine (the beach unit sent its beacon via the buoy to the master station). Connections and beacons were recorded at the master station and were stored in the buoy and beach TNCs. The stored data from the buoy and beach TNCs were time stamped at the time of each connection, which allowed fixing the loss of signal to the support ships track.

Test results found that the beach station was limited to line-of-sight (20 km) and no boundry layer propagation at sea level existed for the 145 MHZ signal. The propagation from the master station existed out to 75 km, with some message retransmission required. The test was carried out using a modified version of Figure 8. The buoy system did not have the pre-amplifier and the transmitter was selected to operate at a low power setting of 1.5 watts (high power setting is 5 watts). The low power setting was used as a further sensitivity test on the system limitations. The final design

will be set on high power to insure signal excess. This test demonstrated that packet telemetry can be used to send data from the transect line to the Point Sur shore station. Atmospheric conditions during both testing periods had normal electromagnetic refraction conditions. The antenna test installations are shown in Appendix M.

b. Testing the buoy in-water

This testing period was used to find out how an integated buoy package might function at sea and what affects the the seas would have on the antenna system. The buoy system package was the same as the first at sea test, but it was packaged for in-water operations. Results indicated the following:

- Vertical buoy stablity is important to minimize antenna motion.
- TNC preprogrammed transmission lengths should be short to reduce data error losses due to antenna motion.
- Buoy system programs needed improved automation timing to prevent the system from getting locked-up in a programming loop.
- Improve the buoys transmitter by operating on high power.
- Install a preamplifier to improve weak signal reception.

2. Antennas

Testing of the antennas focused on the evaluation of the buoy antenna preformance at 52 km over water and under the influence of antenna tilt causing cross polarization gain reductions.

a. Tilt testing of buoy antenna at 52 km

This was the critical test to find out what limitations exist, which will limit the application of this thesis concept.

The last at sea test resulted in re-evaluation of the receiver sensitivity. The receiver sensitivity was tested under two conditions: 1) in its normal configuration and 2) with a commerical preamplifier attached. The test was performed using a RACAL-DANA 9082P SN4192, rf signal generator. Figure 27 illustrates the results of the receiver sensitivity tests. The improved sensitivity (Figure 27) using the preamplifier also improved reception of computer noise from the TNC and the TT4. The EMC procedures discussed earlier were required to improve weak signal enhancement provided by the preamplifier.

Additional opportunities for at-sea testing of the improvements to the buoy transceiver were not available. To test the improvements, two alternative tests were developed: 1) to test the buoy system over 52 km of water between 2 land stations and

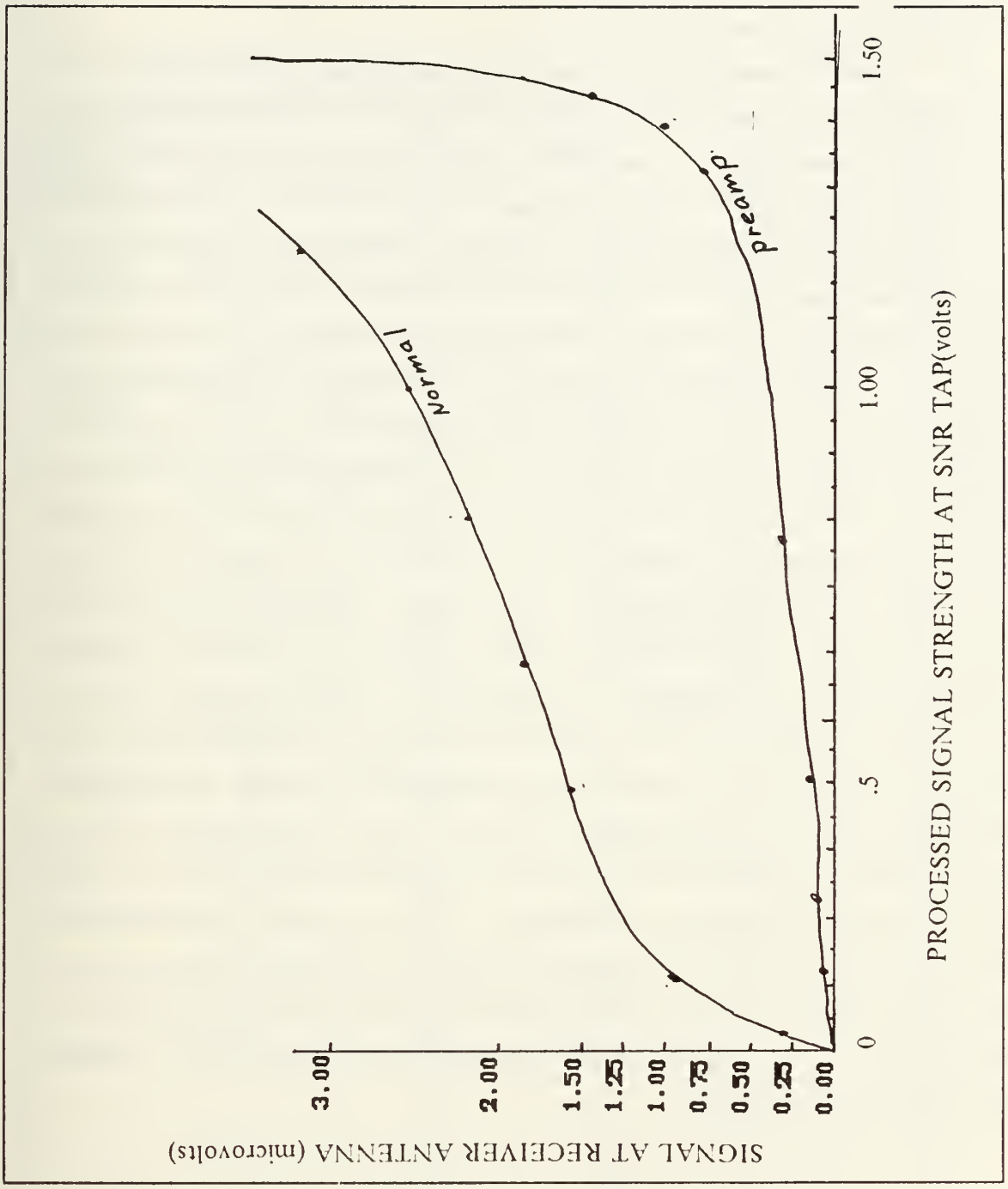


Figure 27. ICOM receiver improvement using a preamplifier: The addition of the preamplifier improved the signal response and also the susceptability to electromagnetic interferrence from the TNC and TT4.

2) to test the buoy system under different antenna tilt conditions to simulate buoy motion at 52 km range between these stations.

Tests were conducted using the antenna in Figure 17, which was at an elevation of 320 feet above sea level, on a radio tower at the Naval Postgraduate School housing area in Monterey, CA. Appendix N shows the antenna installation at NPS. The equipment configuration is shown in Figure 8. Additionally, the TNC and TT4 package and the transceiver package (Figure 24) were connected using the intended 150 feet (Kevlar reinforced cable with 4-28 gage wires) underwater winch cable. The buoy package was operated from Davenport Landing, which is a beach 52 km over water from Monterey, CA. The shore station equipment, in Monterey, was programmed to acknowledge the buoy in Davenport, send a preprogrammed message (which provide time to measure the signal strength in Davenport, CA) and then automatically disconnect from Davenport. When power was applied to the buoy (in Davenport), the buoy would transmit a connect request to Monterey every 15 seconds. Once the buoy was connected, a reading of the SNR tap (Figure 12) was taken. The buoy antenna was elevated on a 6 foot pole. At the beach the antenna was tilted to the indicated directions and angles in Table 4. During each 15 second interval a reading was taken from the SNR tap and was logged in Table 4, and the antenna was repositioned for the next reading. From Table 4 the average of all the readings was 1.462 volts with maximum and minimum readings remaining within 4% of the average. Comparing the SNR tap readings to Figure 27 indicated that sufficient excess signal exsists over a 52 km path over water when the preamplifier is connected. This test indicated that the received signal at the antenna was about 1 microvolt. Without the preamplifier, the 1 microvolt signal would only provide about .13 volts at the SNR tap with the result of insufficient signal to drive the TNC. Readings at the Monterey site also indicated that a full scale signal excess was being received.

Table 4. **RESULTS OF TILT TEST OF BUOY ANTENNA.:** The values recorded are the voltage readings taken from the SNR tap shown in Figure 12, and the significance of the values are shown in Figure 27.

TILT DIRECTION	TILT ANGLE	STUB TOWARD	STUB RIGHT	STUB AWAY	STUB LEFT
Vertical	0	1.46	1.52	1.50	1.50
North	10	1.49	1.50	1.51	1.51
	20	1.48	1.45	1.47	1.48
	35	1.43	1.47	1.43	1.46
	50	1.39	1.44	1.42	1.45
South	10	1.49	1.49	1.50	1.49
	20	1.47	1.50	1.46	1.47
	35	1.47	1.49	1.47	1.49
	50	1.44	1.42	1.43	1.47
East	10	1.49	1.47	1.45	1.43
	20	1.48	1.49	1.49	1.48
	35	1.46	1.45	1.44	1.46
	50	1.40	1.44	1.43	1.43
West	10	1.45	1.46	1.50	1.51
	20	1.46	1.49	1.40	1.46
	35	1.47	1.47	1.48	1.50
	50	1.42	1.37	1.46	1.45
Northwest	10	1.41	1.49	1.50	1.52
	20	1.46	1.50	1.49	1.42
	35	1.47	1.39	1.45	1.49
	50	1.43	1.45	1.46	1.46
Southwest	10	1.48	1.52	1.49	1.52
	20	1.50	1.52	1.50	1.52
	35	1.47	1.49	1.49	1.49
	50	1.46	1.44	1.45	1.36
Northeast	10	1.50	1.48	1.50	1.51
	20	1.47	1.50	1.48	1.51
	35	1.49	1.35	1.46	1.45
	50	1.39	1.45	1.43	1.38
Southeast	10	1.45	1.46	1.50	1.45
	20	1.50	1.51	1.49	1.51
	35	1.48	1.45	1.47	1.43
	50	1.43	1.44	1.20	1.42

3. Acoustic link (Aanderaa Instruments Inc.)

a. Testing acoustic link error rate

The fact that data could be transferred from a recording current meter to a remote hydrophone lead to the idea of telemetry transmissions to shore. This thesis has demonstrated that *decoded hydrophone signals* can be transmitted error-free back to a shore station. Unfortunately, the Aanderaa Acoustic Link was not designed to be a reliable and error free acoustic link for passing data for more than about 100 meters in water. The result is an error-free telemetry system supporting an error-prone acoustic link.

The Aanderaa Acoustic Link transducer model 2247 SN 426 was tested off shore at Point Sur, CA, at the transect point P3 from the R/V Point Sur. The experiment was set up to find the limitations of the acoustic link. The test used a RCM8 recording current meter which was attached to the cage of a CTD. The cage was lowered over the side and was used to provide depth control for the RCM8. The acoustic transducer was lowered along the CTD winch cable, which insured vertical alignment between the RCM8 and the transducer and provided an ability to calculate the length of the acoustic path. The pulse duration coded acoustic signal, from the RCM8 to the hydrophone, was decoded using the TT4 and the program in Appendix C.

By maintaining the hydrophone at 8 meters below the surface and lowering the RCM8, it was found, through repeated depth changes, that the error free acoustic link range was 80 meters or less. Beyond 80 meters, a full record could not be obtained.

Woods Hole Oceanographic Institution conducted a similar test, but used the Aanderra deck recording equipment. The results were similar, except that they experienced greater error rates. They attibuted the error rates to the synch pulse errors and to the deck units failure to not always decode the binary data into decimal form for the printout. Their conclusion is that the present system is not useful for serious data telemetry for general applications. (Frye, 1988)

b. Program to reduce error rate

The error rates and dropouts that occured using Aanderaa deck unit and printer with the Aanderaa hydrophone can be reduced by using the error checking program in Appendix C. The program is written in TTBASIC for program execution on the TT4. The timing loops are easily implemented and provided a simple error checking routine. The routine is outlined in Figure 28

.

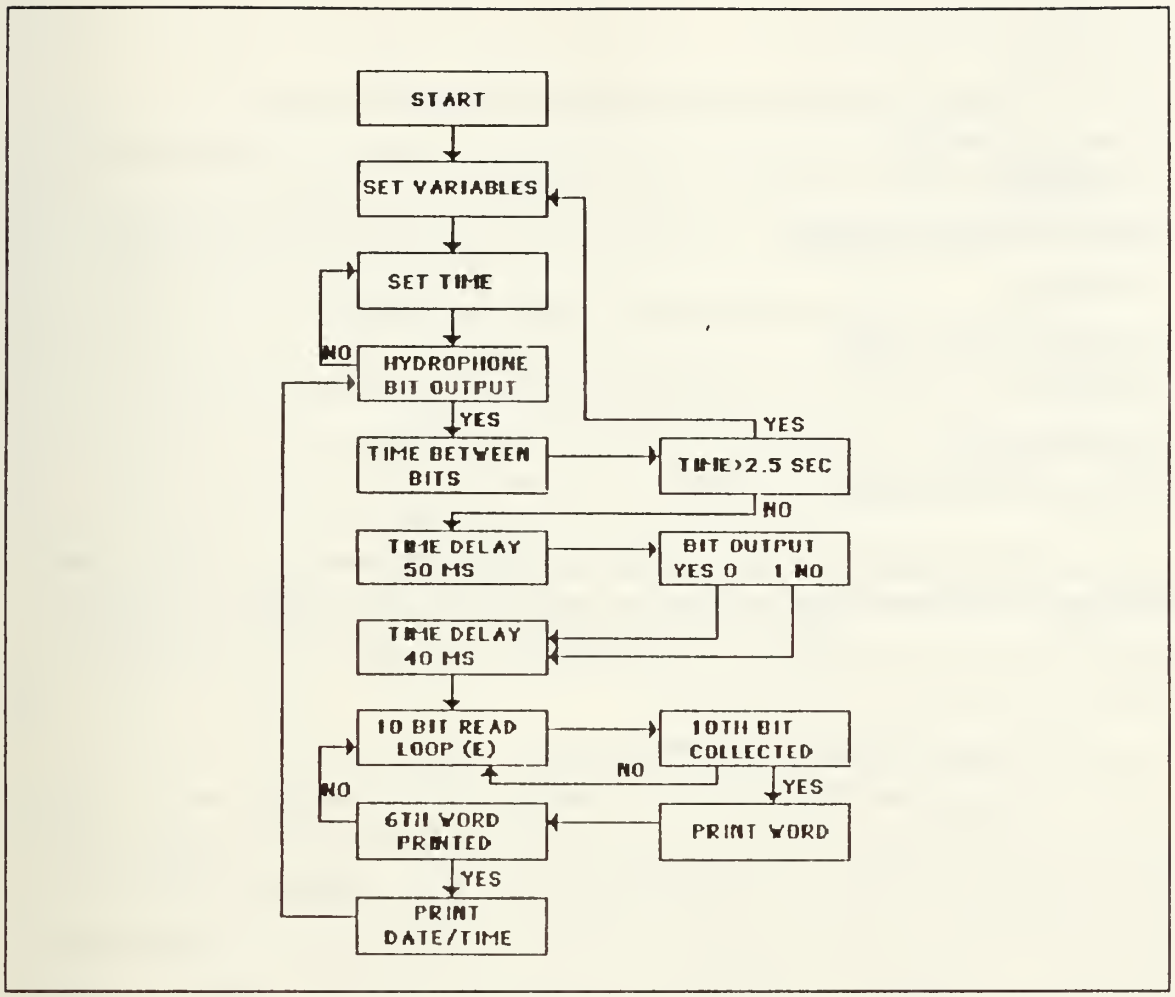


Figure 28. Block diagram of the program which decodes the Aanderaa acoustic pulse duration code.

To ensure what data was sent and when the errors occured, the TT4 decoder program was developed to sense the timing sequence and reject out-of-sequence noise (any 16 KHZ noise triggers an output from the hydrophone, i.e., jiggling a set of keys in front of the hydrophone will result in the sending of strings of 0's and 1's). Correct sequenced data generates the channel number and title followed by the 10-bit binary string, which prints out as follows:

- Channel 1 Reference
- 1111001100
- Channel 2 Temperature

- 1001001111
- Channel 3 Conductivity
- 1000001000
- Channel 4 Pressure
- 0001010000
- Channel 5 Vector Direction
- 1001001101
- Channel 6 Vector Speed
- 0000001011
- End of Record
- Time is 0-00-00 Ref data is 1/1/80

The 10-bit binary word is read from the least significant digit (LSD) on the left to the most significant digit (MSD) on the right. The record is stopped on the 61st bit and the time and date is recorded. This program is not a cure, only an improvement. The cure will be an improved acoustic link.

c. Proposed alternative to the acoustic link

The Aanderaa RCM8 has an alternative source for sending data by using the *2994 electrical connector.* The same pulse duration code sequence is sent to the electrical connector as well as the acoustic transducer. Future designs should look to fiber optic alternatives for data transfer to the underwater winch. A rotating optical coupling joint may permit all the RCM8s on an array to be linked by a single fiber optic cable, without restricting the movement of the RCM8.

V. RECOMMENDATIONS AND CONCLUSIONS

A. RECOMMENDATIONS FOR ADDITIONAL THESIS TOPICS AT NPS:

- Continue mechanical engineering development of a pop-up buoy canister that will minimize antenna motion.
- Continue the mechanical engineering of the underwater winch.
- Continue the electronic engineering development of a reliable acoustic link, which can copy all transmissions from current meters on a vertical array.
- Continue telemetry environmental evaluation on the affects of trapping and multi-path interferrence influences, and collect statistical information on bit-error rate over a several months of telemetry operations.
- Continue to monitor the changes in telemetry equipment and take advantage of lower power units operating at higher baud rates, which would result in much lower transmitter power for the same length of transmitted data.

B. CONCLUSIONS:

This thesis demonstrates that a VHF NBFM packet telemetry system, under automated software control, is a practical tool for near shore telemetry of in situ oceanographic data. The availability of this near real time data collection ability offers the opportunity for researchers to investigate and develop new methodologies for nowcasting, forecasting and hindcasting of near shore ocean current events. Near real time data collection from buoys means that researchers can collect high resolution SSM/I, SST and AVHRR satellite data at the time of an event. At present high resolution satellite data is removed (without storage) from source computers after 48-72 hours. Collected satellite data can be used to develop time series investigations before, during and after a mooring event has been detected, thus supporting investigations of undercurrent variability. Data that is collected daily provides verification that a mooring is still operational, offers the ability to conduct experiments of opportunity with other researchers and may lead to the development of expendable moorings.

The basic concepts of the automated packet telemetry systems are available from off-the-shelf technologies. The communications industry is moving forward with higher speed and lower power packet systems. The basic system detailed here can be directly applied to the higher baud rates (9600 baud). This system was developed using 1200 baud telemetry. At the newer 9600 baud, only 1/8 of the transmitting time is needed,

which translates into reduced power consumption and smaller pop-up buoy canister designs.

The objective of this thesis is to augment direct measurement technology by advancing the state-of-the-art in ocean data collection using near real time telemetry. This thesis achieved the following:

- Demonstrated that telemetry equipment can be low cost, have low power consumption and be small enough in size to support a pop-up buoy design.
- VHF NBFM is the best modulation scheme for line-of-sight communications to near shore buoys.
- Packet telemetry offers the best error checking protocol in the environments where communications can be momentarily lost due to wave motion.
- Antenna height above ground is the most effective way to achieve longer line-of-sight communications from shore stations, but not for buoy antennas.
- Methods were developed to overcome electromagnetic compatiblity problems between computer systems and receivers, thus improving the ability to gain a margin of signal excess.
- Evaluation of various batteries where made to determine which battery can best be applied to each system.
- Development of an improved error checking program to read the Aanderaa hydrophone recievers was achieved.
- Development of a program for the ONSET Tattletale Model IV computer to automate the collecting, measuring, storing and telemetry of data was achieved.
- Verification of the design of the hybrid dipole antenna to perform under conditions similar to wave motion influences was made.
- Evaluation of the Aanderaa Acoustic Link was completed and found to be the weakest link to an effective data recovery system.
- A designated frequency of 143.657 MHZ was obtained from the Navy for a five year research period.
- Establishment of a liaison with the U.S. Coast Guard and the California Park Service was made to secure the use of the Point Sur, CA, site for testing.

This thesis involved an ocean engineering investigation which provided an opportunity to investigate instrumentation applications to oceanography. Hopefully this will help advance state-of-the-art oceanography hardware and software towards three dimensional modeling and prediction systems.

APPENDIX A. PROJECT COSTS

UNITS	SERIAL NO.	ITEM	COST
1	07801	ICOM IC-28A	409.95
1	8804330	ASTRON pwr supply	69.95
1	09310	ASTRON pwr supply	69.95
1	65033	ICOM-02AT	279.99
1	09629848	Pre-amp ARR SP144VDG	109.95
1	09630848	Pre-amp ARR SP144VDG	109.95
1	---	Wall 12v pwr supply for TNC's	9.95
1	3001606	DIGIPAC I software	49.95
1	530	Tattletale 4 computer w/Dev Kit	490.00
1	531	Tattletale 4 computer	395.00
1	532	Tattletale 4 computer	395.00
1	7995	PAC-COMM TNC-220	179.95
1	7968	PAC-COMM TNC-220	179.95
1	M0199	PAC-COMM Micropower-2 TNC	179.95
1	---	Cushcraft 230WB antenna	239.95
1	---	100Ft roll Beldon 9913	59.95
4	---	Amphenol 9913 "n" connectors	4.73
1	---	150Ft roll Kevlar/2pair-28g cable	150.00
7	---	Blocks of syntactic foam	------

APPENDIX B. SYSTEM PROGRAM WITH COMMENTS

```
' START PROGRAM THESIS.030
  5 RTIME
'
'SET INTIAL VALUES
  10 D=0: E=0: F=0: L=0: M=0: N=0: P=0: W=0: X=0: G=0: C=0
'
'ENABLE CTRL-S AND CTRL-Q FOR TNC (CTRL-Q TIMEOUT IN 10SEC)
  14 XSHAKE 1000
'
'INITIALIZE SLEEP CYCLE
  16 SLEEP 0
'
'WAIT FOR HYDROPHONE RECORD TO START
  20 IF PIN(13)=0 GOSUB 900
'
'RECYCLE POINT IN PROGRAM FOR EACH RECORD WORD
  25 IF PIN(13)=0 GOSUB 1000
  30 SLEEP 1
'
'CHECK IF 24 HOURS HAVE PASSED SINCE LAST TRANSMISSION
  35 Y=?: I=1: F=(Y/8640000)
  40 IF I=F GOTO 105
'
'RECYCLE AND WAIT FOR HYDROPHONE RECORD START
  50 GOTO 20
'
'PROGRAM INTERUPT VIA CTRL-C (TATTLETALE REQUIREMENT)
 100 STOP
'
'SEQUENCE I TO RECOGNIZE THE NEXT 24 HOUR PERIOD IN LINE 40
 105 I=I+1
'
'GET START TIME; TURN ON RADIO AND TNC; CONNECT TO SHORE STATION
 110 J=60*(?(1)): K=?(0): PSET(15): SLEEP 500: PRINT"C KC3RL": SLEEP200
'
'CHECK TO SEE IF CONNECTED TO SHORE
 170 IF PIN(6)=0 GOTO 190
'
'IF NOT CONNECTED, TRY AGAIN
 182 G=G+1: Z=0
 184 SLEEP 100
 185 IF G=10 GOTO 110
 186 IF G=20 GOTO 110
 187 IF G=30 GOTO110
'
'DISCONNECT IF CAN'T CONNECT TO SHORE
 188 IF G=31 GOTO 390
 189 GOTO 170
'
'START TATTLETALE MEMORY OFF LOAD
 190 A=0
```

```
 200 FOR D= 1 TO W
 210 OTEXT A:ONERR 390
 220 NEXT D
'
'RECORD TRANSMISSION TIME
 270 PRINT'TIME IS ',?(2),':',?(1),' ',?(0):PRINT' ON ',?(4),'/',?(3),'/',?(5)
'
'GUESSING ROUTINE FOR TATTLETALE TO SECURE RADIO AND TNC
 290 I=60*(?(1)):Y=?(0):Z=10*(I+Y)-10*(J+K)
 310 Z=Z+700
 311 SLEEP Z
'
'CHECK TO SEE IF ANY UNAKNOWLODGED PACKETS, IF SO WAIT AGAIN
 314 IF PIN(12)=0 GOTO420
'
'TERMINATE TNC DATA TRANSFER
 330 PRINT 03, 03, 03;
 340 SLEEP 200
'
'TNC DISCONNECT
 350 PRINT"D"
'
'CHECK TO SEE IF SHORE DISCONNECTED
 370 IF PIN(6)=1 GOTO 390
 380 GOTO 311
'
'TURN OFF RADIO AND TNC
 390 PCLR15
 400 SLEEP 3000
 410 GOTO 10
 420 G=G+1:IF G=10 GOTO 390
 440 GOTO310
'
'HYDROPHONE DATA LOGGER ROUTINE START
 900 N=?
 910 Z=2:W=2:O=2:H=2:Q=2:R=2:S=2:T=2:U=2:V=2
'
'INITIAL TIME P
1000 IF P=0 GOTO 1030
'
'ALL OTHER P TIMES AFTER INTIAL P FROM TATTLETALE INITIAL TURN ON
'ALSO SET BINARY 1 (RESET TO 0 IF PULSE IS 81MSEC IN LINE 1070)
1005 B=1:L=?:P=L-M
'
'IF PULSE FROM HYDROPHONE > 2.5SEC, THEN START OVER (BAD DATA CHECK)
1020 IF P>250 GOTO 10
1030 P=1
1060 SLEEP 5
'
'TIME M USED IN NEXT WORD LOOP IN LINE 1005
1065 M=?
'
'CHECK TO SEE IF HYDROPHONE IS STILL ON, IF SO SET BINARY 0
1070 IF PIN(13)=0 B=0
1080 SLEEP 4
'
```

```
'USING INTEGER MATH TO SEQUENCE THROUGH HYDROPHONE TIMING SEQUENCE
1085 C=C+1:E=(M-N+12)/16
1095 IF E=1 Z=B: GOTO 25
1100 IF E=2 W=B: GOTO 25
1105 IF E=3 O=B: GOTO 25
1110 IF E=4 H=B: GOTO 25
1120 IF E=5 Q=B: GOTO 25
1125 IF E=6 R=B: GOTO 25
1130 IF E=7 S=B: GOTO 25
1135 IF E=8 T=B: GOTO 25
1140 IF E=9 U=B: GOTO 25
1145 IF E=10 V=B: GOTO 20
'
'STORING HYDROPHONE DATA IN DATA LOGGER, AND COUNTING RECORDS
1155 IF C=10 STOREA,"CH 1 ",Z,W,O,H,Q,R,S,T,U,V:W=W+1
1175 IF C=20 STOREA,"CH 2 ",Z,W,O,H,Q,R,S,T,U,V:W=W+1
1184 IF C=30 STOREA,"CH 3 ",Z,W,O,H,Q,R,S,T,U,V:W=W+1
1195 IF C=40 STOREA,"CH 4 ",Z,W,O,H,Q,R,S,T,U,V:W=W+1
1205 IF C=50 STOREA,"CH 5 ",Z,W,O,H,Q,R,S,T,U,V:W=W+1
1215 IF C=60 STOREA,"CH 6 ",Z,W,O,H,Q,R,S,T,U,V:W=W+1
1225 IF C=60 STOREA,"TIME IS ",?(2),':',?(1),':? ',?(0):W=W+1
1226 IF C=60 STOREA,"REF DATE IS ",?(4),'/',?(3),'/',?(5):W=W+1
1230 IF C=61 C=0
'
'SLEEP COMPUTER FOR 25 MINUTES, THEN WAKE UP TO WAIT FOR HYDROPHONE DATA
1235 SLEEP 150000
1240 RETURN
```

APPENDIX C. HYDROPHONE PRINT PROGRAM

```
  10
W=0: Z=0: D=0: E=0: F=0: H=0: L=0: M=0: N=0: O=0: P=0: Q=0: R=0: S=0: T=0: U=0: V=0
  14 RTIME: C=0: N=?
  16 SLEEP 0
  20 IF PIN(13)=0 GOSUB 1000
  50 GOTO 15
 100 STOP
1000 IF P=0 GOTO 1030
1005 B=1: L=?: P=L-M
1020 IF P>250 GOTO 10
1030 P=1
1060 SLEEP 5
1065 M=?
1070 IF PIN(13)=0 B=0
1080 SLEEP 4
1085 C=C+1: D=(C/10)*10: E=C-D
1095 IF E=1 Z=B: IF E=2 W=B: IF E=3 O=B: IF E=4 H=B: IF E=5 Q=B
1100 IF E=6 R=B: IF E=7 S=B: IF E=8 T=B: IF E=9 U=B: IF E=0 V=B
1150 IF C=1 PRINT"CHANNEL 1 REFERENCE"
1155 IF C=10 PRINT Z,W,O,H,Q,R,S,T,U,V: PRINT: PRINT"CHANNEL 2 TEMPERATURE"
1175 IF C=20 PRINT Z,W,O,H,Q,R,S,T,U,V: PRINT: PRINT"CHANNEL 3 CONDUCTIVITY"
1184 IF C=30 PRINT Z,W,O,H,Q,R,S,T,U,V: PRINT: PRINT"CHANNEL 4 PRESSURE"
1195 IF C=40 PRINT Z,W,O,H,Q,R,S,T,U,V: PRINT: PRINT"CHANNEL 5 VECTOR DIRECTION"
1205 IF C=50 PRINT Z,W,O,H,Q,R,S,T,U,V: PRINT: PRINT"CHANNEL 6 VECTOR SPEED"
1215 IF C=60 PRINT Z,W,O,H,Q,R,S,T,U,V: PRINT: PRINT"END OF RECORD"
1225 IF C=60 PRINT"TIME IS ",?(2),':',?(1),':? ',?(0);
1226 IF C=60 PRINT"   REF DATE IS ",?(4),'/',?(3),'/',?(5)
1230 IF C=61 C=0: PRINT: PRINT
1240 RETURN
```

APPENDIX D. TEMPERATURE/RADIO CYCLE PROGRAM

```
 10 XSHAKE 1000
 20 RTIME
 30 X=0: G=0
 50 FORA=1 TO 100
 60 SLEEP 10
 70 STORE X,#2,CHAN(10)
 80 NEXT A
 90 GOTO 110
100 STOP
110 J=60*(?(1)): K=?(0): PSET(15): SLEEP 500: PRINT"C KC3RL": SLEEP200
170 IF PIN(6)=0 GOTO 190
182 G=G+1
184 SLEEP 100
185 IF G=20 GOTO 110
186 IF G=30 GOTO 110
187 IF G=30 GOTO110
188 IF G=31 GOTO 390
189 GOTO 170
190 X=0: G=0
200 FOR B= 1 TO 100
210 A=TEMP(GET(X,#2))
220 A=A*(9/5)+320
230 PRINT #4,A/10,'.',#1,A%10;
240 IF B%10=0 PRINT
250 NEXT B
270 PRINT'TIME IS ',?(2),':',?(1),' ',?(0): PRINT' ON ',?(4),'/',?(3),'/',?(5)
290 I=60*(?(1)): Y=?(0): Z=10*(I+Y)-10*(J+K)
310 Z=Z+700
311 SLEEP Z
314 IF PIN(12)=0 GOTO420
330 PRINT 03, 03, 03;
340 SLEEP 200
350 PRINT"D"
370 IF PIN(6)=1 GOTO 390
380 GOTO 360
390 PCLR15
400 SLEEP 3000
410 GOTO 20
420 G=G+1: IF G=10 GOTO 390
440 GOTO310
```

APPENDIX E. SYSTEM PROGRAM TO STORE DATA TEST

```
  5 RTIME
 10 D=0: E=0: F=0: L=0: M=0: N=0: P=0: W=0: X=0: G=0: C=0
 14 XSHAKE 1000
 16 SLEEP 0
 20 IF PIN(13)=0 GOSUB 900
 25 IF PIN(13)=0 GOSUB 1000
 30 SLEEP 1
 35 Y=?: I=1: F=(Y/8640000)
 40 IF I=F GOTO 105
 50 GOTO 20
100 STOP
105 I=I+1
110 J=60*(?(1)): K=?(0): PSET(15): SLEEP 500: PRINT"C KC3RL": SLEEP200
170 IF PIN(6)=0 GOTO 190
182 G=G+1: Z=0
184 SLEEP 100
185 IF G=10 GOTO 110
186 IF G=20 GOTO 110
187 IF G=30 GOTO110
188 IF G=31 GOTO 390
189 GOTO 170
190 A=0
200 FOR D= 1 TO W
210 OTEXT A
220 NEXT D
270 PRINT'TIME IS ',?(2),':',?(1),' ',?(0): PRINT' ON ',?(4),'/',?(3),'/',?(5)
290 I=60*(?(1)): Y=?(0): Z=10*(I+Y)-10*(J+K)
310 Z=Z+700
311 SLEEP Z
314 IF PIN(12)=0 GOTO420
330 PRINT 03, 03, 03;
340 SLEEP 200
350 PRINT"D"
370 IF PIN(6)=1 GOTO 390
380 GOTO 311
390 PCLR15
400 SLEEP 3000
410 GOTO 10
420 G=G+1: IF G=10 GOTO 390
440 GOTO310
900 N=?
910 Z=2: W=2: O=2: H=2: Q=2: R=2: S=2: T=2: U=2: V=2
1000 IF P=0 GOTO 1030
1005 B=1: L=?: P=L-M
1020 IF P>250 GOTO 10
1030 P=1
1060 SLEEP 5
1065 M=?
1070 IF PIN(13)=0 B=0
1080 SLEEP 4
1085 C=C+1: E=(M-N+12)/16
```

```
1095 IF E=1 Z=B: GOTO 25
1100 IF E=2 W=B: GOTO 25
1105 IF E=3 O=B: GOTO 25
1110 IF E=4 H=B: GOTO 25
1120 IF E=5 Q=B: GOTO 25
1125 IF E=6 R=B: GOTO 25
1130 IF E=7 S=B: GOTO 25
1135 IF E=8 T=B: GOTO 25
1140 IF E=9 U=B: GOTO 25
1145 IF E=10 V=B: GOTO 20
1155 IF C=10 STOREA,"CH 1 ",Z,W,O,H,Q,R,S,T,U,V:W=W+1
1175 IF C=20 STOREA,"CH 2 ",Z,W,O,H,Q,R,S,T,U,V:W=W+1
1184 IF C=30 STOREA,"CH 3 ",Z,W,O,H,Q,R,S,T,U,V:W=W+1
1195 IF C=40 STOREA,"CH 4 ",Z,W,O,H,Q,R,S,T,U,V:W=W+1
1205 IF C=50 STOREA,"CH 5 ",Z,W,O,H,Q,R,S,T,U,V:W=W+1
1215 IF C=60 STOREA,"CH 6 ",Z,W,O,H,Q,R,S,T,U,V:W=W+1
1225 IF C=60 STOREA,"TIME IS ",?(2),':',?(1),':? ',?(0):W=W+1
1226 IF C=60 STOREA,"REF DATE IS ",?(4),'/',?(3),'/',?(5):W=W+1
1230 IF C=61 C=0
1235 SLEEP 150000
1240 RETURN
```

APPENDIX F. SYSTEM PROGRAM TO PRINT DATA TEST

```
  10
W=0 : Z=0 : D=0 : E=0 : F=0 : H=0 : L=0 : M=0 : N=0 : O=0 : P=0 : Q=0 : R=0 : S=0 : T=0
: U=0 : V=0

  11 XSHAKE 1000
  14 RTIME : C=0 : G=0 : X=0
  15 N=?
  16 SLEEP 0
  20 IF PIN(13)=0 GOSUB 1000
  40 Z=W
  50 W=(N/8640000)
  60 IF (W-Z)=0 GOTO 15
  70 GOTO 110
 100 STOP
 110 J=60*(?(1)) : K=?(0) : PSET(15) : SLEEP 500 : PRINT"C KC3RL" : SLEEP200
 170 IF PIN(6)=0 GOTO 190
 182 G=G+1
 184 SLEEP 100
 185 IF G=20 GOTO 110
 186 IF G=30 GOTO 110
 187 IF G=30 GOTO110
 188 IF G=31 GOTO 390
 189 GOTO 170
 190 X=0 : G=0
 200 FOR B= 1 TO X
 210 GET (X,#2)
 230 PRINT
 250 NEXT B
 270 PRINT'TIME IS ',?(2),' :',?(1),' ',?(0) : PRINT' ON ',?(4),'/',?(3),'/',?(5)
 290 I=60*(?(1)) : Y=?(0) : Z=10*(I+Y)-10*(J+K)
 310 Z=Z+700
 311 SLEEP Z
 314 IF PIN(12)=0 GOTO420
 330 PRINT 03, 03, 03;
 340 SLEEP 200
 350 PRINT"D"
 370 IF PIN(6)=1 GOTO 390
 380 GOTO 360
 390 PCLR15
 400 SLEEP 3000
 410 GOTO 20
 420 G=G+1 : IF G=10 GOTO 390
 440 GOTO310
1000 IF P=0 GOTO 1030
1005 B=1 : L=? : P=L-M
1020 IF P>250 GOTO 10
1030 P=1
1060 SLEEP 5
1065 M=?
1070 IF PIN(13)=0 B=0
1080 SLEEP 4
```

```
1085 C=C+1 :D=(C/10)*10 :E=C-D
1095 IF E=1 Z=B
1100 IF E=2 W=B
1105 IF E=3 O=B
1110 IF E=4 H=B
1120 IF E=5 Q=B
1125 IF E=6 R=B
1130 IF E=7 S=B
1135 IF E=8 T=B
1140 IF E=9 U=B
1145 IF E=0 V=B
1150 IF C=1 PRINT"CHANNEL 1 REFERENCE"
1155 IF C=10 PRINT Z,W,O,H,Q,R,S,T,U,V :PRINT :PRINT"CHANNEL 2 TEMPERATURE"
1175 IF C=20 PRINT Z,W,O,H,Q,R,S,T,U,V :PRINT :PRINT"CHANNEL 3 CONDUCTIVITY"
1184 IF C=30 PRINT Z,W,O,H,Q,R,S,T,U,V :PRINT :PRINT"CHANNEL 4 PRESSURE"
1195 IF C=40 PRINT Z,W,O,H,Q,R,S,T,U,V :PRINT :PRINT"CHANNEL 5 VECTOR DIRECTION"
1205 IF C=50 PRINT Z,W,O,H,Q,R,S,T,U,V :PRINT :PRINT"CHANNEL 6 VECTOR SPEED"
1215 IF C=60 PRINT Z,W,O,H,Q,R,S,T,U,V :PRINT :PRINT"END OF RECORD"
1225 IF C=60 PRINT"TIME IS ",?(2),' :',?(1),' :? ',?(0);
1226 IF C=60 PRINT"   REF DATE IS ",?(4),'/',?(3),'/',?(5)
1230 IF C=61 C=0 :PRINT :PRINT
1240 RETURN
```

APPENDIX G. PICTURES OF THE DATA LOGGER AND TNC HARDWARE CANISTER

The TNC fills the bottom of the canister and the data logger is mounted over the TNC board.

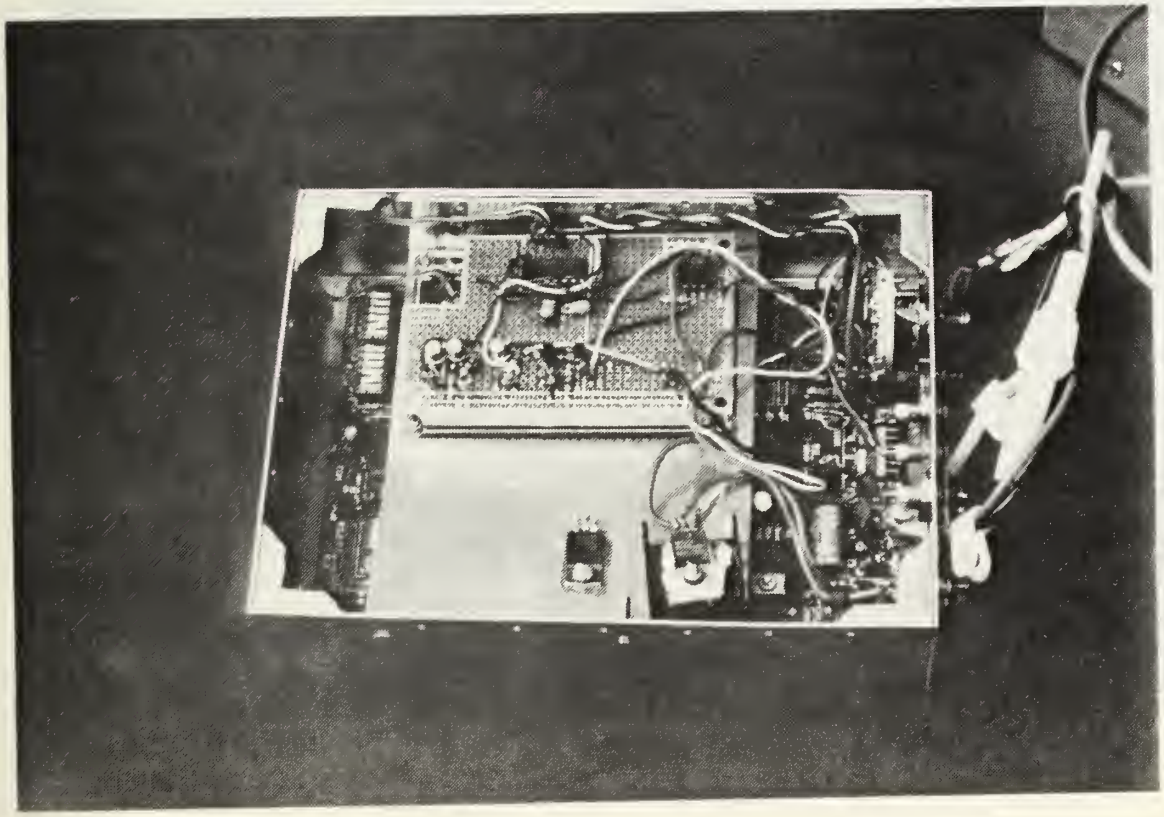
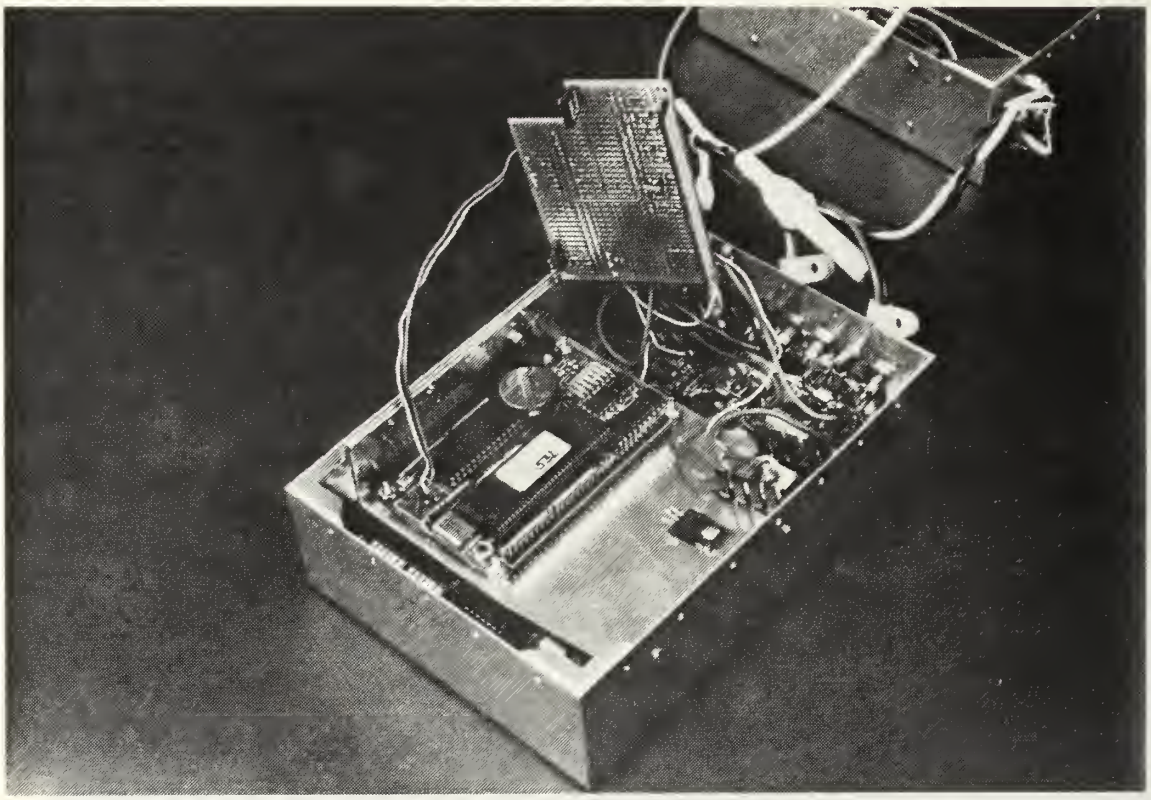


Illustration showing the data logger protection circuit board separated from the data logger.



APPENDIX II. ICOM SPECIFICATIONS

Dimensions	116.5mm(H) x 65mm(W) x 35mm(D) Without power pack Attendant power pack, IC-BP3 49mm(H) x 65mm(W) x 35mm(D)
Weight	515g (IC-02A: 495g) including power pack, IC-BP3 and flexible antenna
TRANSMITTER	
Output power	HIGH: 3W at 8.4V (5W at 13.2V) LOW: 0.5W at 8.4V ~ 13.2V
Emission mode	$16F_3$ (F3E 16K0)
Modulation system	Variable reactance frequency modulation
Max. frequency deviation	±5KHz
Spurious emission	More than 60dB below carrier
Microphone	Built-in Electret condenser microphone Optional Speaker-microphone (IC-HM9) and Headset (HS-10) can be used
Operating mode	Simplex Duplex (Any in-band frequency separation programmable)
RECEIVER	
Receiving system	Double-conversion superheterodyne
Modulation acceptance	$16F_3$ (F3E 16K0)
Intermediate frequencies	1st: 16.9MHz 2nd: 455KHz
Sensitivity	Less than 0.25μV for 12dB SINAD Less than 0.3μV for 20dB Noise quieting
Squelch sensitivity	Less than 0.1μV
Spurious response rejection ratio	More than 60dB
Selectivity	More than ±7.5KHz at −6dB point Less than ±15KHz at −60dB point
Audio output power	More than 500mW (at 8 ohms 10% distortion)
Audio output impedance	8 ohms

Figure 29. Listing of the specifications of the ICOM 02AT.

APPENDIX I. FREQUENCY COORDINATION

A. INITIATING MESSAGE FOR A NAVY FREQUENCY ALLOCATION.

```
RTTUZYUW RUWJAGA4732 3030445-UUUU--RHWISUU.
ZNR UUUUU
R 290445Z OCT 88 ZYB
FM NAVPGSCOL MONTEREY CA
TO NAVFRCOORD NTCC OAKLAND CA
INFO NAVFRCOORD WESTERN US PT MUGU CA
NAVCAMS EASTPAC HONOLULU HI
COMTHIRDFLT
CINCPACFLT PEARL HARBOR HI
BT
UNCLAS //N02420//
SUBJ: FREQUENCY PROPOSAL-USN
A.  NTP-6(B), ANNEX D
1.  SUBMITTED IAW REF A.
    005. U
    010. N
    110. M140-150.8 (ONE FREQUENCY REQUIRED)
    113. FLE
    114. 16K0F2D
    115. W25
    130. 3
    140. 890120
    200. USN
    201. CINCPACFLT
    202. PACFLT
    204. NFCDAK
    206. NAVPGSCOL
    207. NAVPGSCOL
    208. N62271
    209. NFCWUS
    300. CA
    301. POINT SUR
    303. 361814N/1215310W
    340. C, ICM'28A
    341. 10, NET
    354. YAGI
    355. CUSHCRAFT 215WB
    357. 16
    358. 360
    359. 40
    362. 270
    363. V
```

100. CA
401. PAC
403. 362000N/1222820W
440. C, ICM'.02AT
454. HYBRID DIPOLE
455. DEVELOPMENTAL HYBRID DIPOLE
457. 3
458. 5
459. 5
462. ND
463. V
502. OCEANOGRAPHY DEPARTMENT, US NAVAL POSTGRADUATE SCHOOL, CA, IS CONDUCTING A FIVE YEAR, ONR SPONSORED, RESEARCH PROGRAM TO MONITOR OFFSHORE CURRENT PROFILES 5 TO 30 MILES WEST OF POINT SUR, CA. TO OBTAIN FIXED MOORED BUOY DATA DAILY WILL REQUIRE A ONCE PER DAY TRANSMISSION OF DIGITAL TELEMETRY DATA FROM AN OFFSHORE BUOY USING 1200 BAUD PACKET SWITCHING TECHNOLOGY. INITIAL TEST OF THIS TELEMETRY CONCEPT WILL REQUIRE SEVERAL SHORT (5-10 MINUTE) TELEMETRY TRANSMISSIONS PER DAY. FROM FEB 89 TO FEB 94, ONLY ONE TELEMETRY TRANSMISSION PERIOD PER DAY IS SCHEDULED, WITH A TRANSMISSION PERIOD REQUIREMENT OF 15 MINUTES. NO VOICE COMMUNICATIONS REQUIRED. THE BUOY TELEMETRY SYSTEM WILL BE COMPUTER CONTROLLED, WITH MONITORING FUNCTIONS AT NPS. A BUOY BACKUP TRANSMITTER TIME-OUT SYSTEM WILL BE USED TO PREVENT THE 5 WATT TRANSMITTER FROM LOCKING-UP IN TRANSMIT.
801. NFC OAKLAND 6 OCT 88.
POINT SUR IS A STATE PARK. THE USCG HAS AN ANTENNA TOWER IN THE PARK WHICH IS SUITABLE FOR ANTENNA INSTALLATION. COORDINATION BETWEEN THE PARK SERVICE (RANGER IN CHARGE JIM RITTER) AND THE USCG HAS BEEN ESTABLISHED. FURTHER SITE COORDINATION REQUIRES AN ASSIGNED FREQUENCY.
803. STEVE RAMP, A/V 878-3162

2. SAME AS PARAGRAPH 1. EXCEPT:
115. W5
300. CA
301. PAC
303. 362000N/1222820W
340. C, ICM'.02AT
354. HYBRID DIPOLE
341. 10, NET
355. DEVELOPMENTAL HYBRID DIPOLE
357. 3

```
     358. 5
     359. 5
     362. ND
     363. V
     400. CA
     431. POINT SUR
     403. 361814N/1216310W
     440. C, ICM'28A
     454. YAGI
     455. CUSHCRAFT 215 WB
     457. 16
     458. 360
     459. 40
     462. 270
     463. V
BT
#4732
```

B. FINAL APPROVAL MESSAGE FOR 143.675 MHZ.

```
   PT 00155                 153  222653

PTTUZYUW RUILSSGG8609 1532130-UUUUU--RUWJAGA.
ZNR UUUUU
S 0212137 JUN 89 ZYB
FM NAVEMSCEN WASHINGTON DC
TO RUWFPAA/NAVERCOORD WESTERN US PT MUGU CA
INFO RUWJAGA/NAVPGSCOL MONTEREY CA
RUHPSAA/NAVCAMS EASTPAC HONOLULU HI
RHHMBPA/CINCPACFLT PEARL HARBOR HI
RUWNFMA/NAVERCOORD NTCC OAKLAND CA
RUEPAEA/ECAC ANNAPOLIS MD
BT
UNCLAS //N02410//
SUBJ:  TEMPORARY FREQUENCY ASSIGNMENT - USN
A.  NAVERCOORD WESTERN US PT MUGU CA 0717137 FEB 89
B.  PHONECON G. WOLLEMAN (NECWUS)/A. DEFILIPPIS (NAVEMSCEN) OF
    3 APR 89
C.  PHONECON CDR MCKINNEY (NAVPGSCOL)/A. DEFILIPPIS (NAVEMSCEN) OF
    10 APR 89
1. 005. U
   010. N
   102. NA91251
   110. M143.675

PAGE 02 RUILSSGG8609 UNCLAS
   113. MOH
   114. 16K0F2D
   115. W25
   130. 1
   141. 9406
   144. Y
   145. 0
   200. USN
   202. PACFLT
   204. NECOAK
   207. NAVPGSCOL
   208. N62271
   209. NECWUS
   300. CA
   301. POINT SUR
   302. 361814N1215316W
   306. 40R
   340. C.T.C.S.P.A.
```

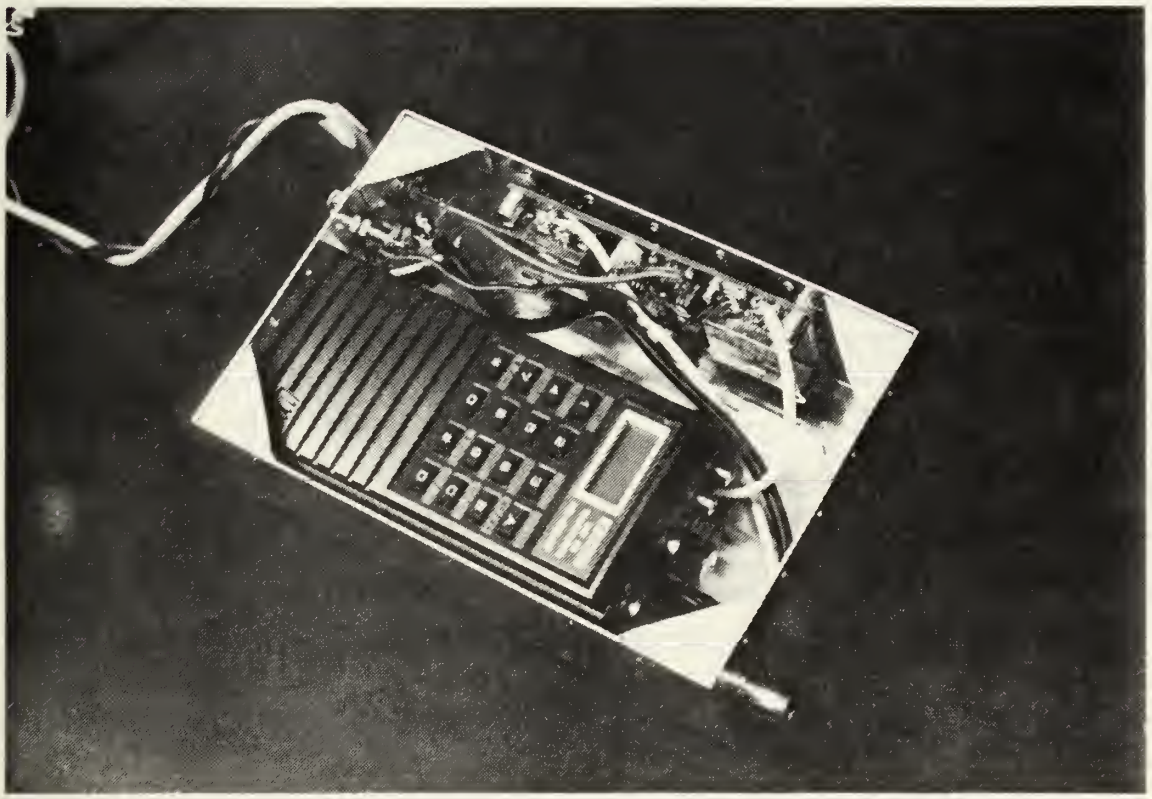
```
    341. 17.MFT
    400. CA

PAGE 03 RULSSGG8609 UNCLAS
    401. POINT SUR
    403. 361814N1215310W
    440. C.ICMG2AT
    502. OCEANOGRAPHY DEPARTMENT IS CONDUCTING A FIVE YEAR RESEARCH
    502. PROGRAM TO MONITOR OFFSHORE CURRENT PROFILES.
    503. OCEAN CURRENTS PROFILE STUDY
    701. 321
    702. N-0233-89
BT
#8609

NNNN
```

APPENDIX J. POP-UP BUOY ELECTRONICS LESS BATTERY, ANTENNA AND BUOY CANISTER

The pop-up canister will contain only the ICOM 02AT transceiver, ADVANCED RESEARCH RECEIVER preamplifier, battery and hybrid antenna.



APPENDIX K. PACKET PROTOCOL DEFAULT SETTING CHANGES

A. SHORE STATION TNC CHANGES:

- *Transparent mode* is required for file transfer packet operations and requires: 8BITCONV (ON), AWLEN (8), CONMODE (TRAN), ECHO (OFF), LCOK (OFF), NEWMODE (ON), PARITY (0), STRAT (S13), and TRFLOW (ON).
- Station recognition and identification require: BUDLIST (ON), CTEXT (NPS1 MOORING), LCALLS (NPS2,NPS3), MRPT (OFF), MYCALL (NPS1)
- Timing interval for best weak signal operation requires: FRACK (5), MAXFRAME (1), RETRY (15), RESPTIME (10)

B. BUOY TNC CHANGES:

- *Transparent mode* is required for file transfer of packet operations and require: 8BITCONV (ON), AWLEN (8), CONMODE (TRAN), ECHO (OFF), LCOK (OFF), NEWMODE (ON), PARITY (0), START (S13), and TRFLOW (ON)
- Station recognition and identification require: BUDLIST (ON), LCALLS (NPS1, NPS3), MRPT (OFF), MYCALL (NPS2)
- Timing interval for best weak signal operation require: FRACK (5), MAXFRAME (1), RETRY (15), RESPTIME (10)

APPENDIX L. ANTENNA SPECIFICATIONS

Forward Gain	18.5 dBd
Front to Back Ratio	24 dB
E-Plane Beamwidth	2 x 17°
H-Plane Beamwidth	2 x 9°
Side Lobe Attenuation	greater than 60 dB
SWR Less Than	1.2:1 typical
Impedance	50 ohms
Recommended Stacking Distance (boom to boom)	H-Plane 10'10" (3.3m)
Weight	22 lb. (10 kg)
Length	15 ft. (4.6m)
Turning Radius	10 ft. (3m)
Wind Survival	100 + MPH (160 + km/h)
Wind Surface Area	4.0 sq. ft. (.8 sq. m)

Figure 30. Specifications for the Cushcraft Boomer Antenna.

APPENDIX M. PICTURES OF ANTENNA TEST INSTALLATIONS AT POINT SUR, CA

A. ILLUSTRATION OF THE BEACH TEST ANTENNA

For the first testing period at Point Sur, CA, the Cushcraft model 230 WB antenna system was split into two sections. One section was installed on the beach and the other section was installed at the top of Point Sur, near the left hand tower in the picture.

B. ILLUSTRATION OF THE TEST ANTENNA ON THE TOP OF POINT SUR.

For both test periods at Point Sur, only half of the Cushcraft 230 WB antenna was used as illustrated below.

APPENDIX N. CUSHCRAFT 230 WB ANTENNA INSTALLATION AT THE NPS MARS STATION

The antenna in Figure 17 is installed on the radio tower at the NPS MARS station in the La Mesa housing area. The antenna is on a heading of 310 degrees, pointing towards Davenport, CA, in preperation for the antenna tilt test. This is the antenna configuration to be installed at Point Sur, CA, on the tower illustrated in Figure 18.

APPENDIX O. POINTS OF CONTACT

Chis Neuman	AANDERAA Instuments 30F Commerce Way Woburn, MA 07801	508-933-8120
Dale Pilsbury	Oregan State University Dept of Oceanography Corvallis, OR 97331	503-754-2207
Ed Webb	Texas A&M College of Geophysics College Station, TX 77843-3146	409-845-3366
Dave Brooks-Prof	Texas A&M College of Geophysics College Station, TX 77843-3146	409-845-5527
John Stidd Jack Dower-Pres	Cortland Cable PO Box 330 Cortland, NY 13045	607-753-8276
Jim Hanlon Kevin McClurg	ENDECO Marion, MA	508-748-0366
Thomas McCord	NPS Lab Manager Code 69RD Monterey, CA 93943	646-2369 A/V-878-2369
LCDR Ric Barns	Officer in Charge Submarine Rescue Unit San Diego, CA	A/V-951-7595
PO1 Rouse USCG	Commander USCG Group MTRY Lighthouse Ave. Monterey, CA 93940	647-7300 100
Dan Frye	WHOI Woods Hole, MA 02543	508-548-1400 x2658
Bruce Mertz	USN Freq Corrdinator	A/V-836-4602
Fritz	Point Sur Facility	625-5606
Mel Briscoe-Prof	ONR Code 1122PO 800 N Annex St. Arlington, VA 22219	202-696-4441

Tex Ritter Jim Pete	Big Sur Park HQ Pfeiffer Big Sur State Park Big Sur, CA 93920	408-667-2316
Jim Valdez-EE	WHOI Woods Hole, MA 02543	508-548-1400
Lon Hocker	ONSET Computer Corp PO Box 1030 N. Falmouth. MA 02556	617-563-2267
John Dahlen	DRAPER Lab	617-258-1316
Jim Layne	REPCO, Incorporated 2421 N. Orange Blossom Trail Orlando, FL 32804-4806	407-843-8484
	HYDROPRODUCTS	619-792-1031
John Anderson	Polar Research Labs Larpinteria, CA	805-684-0441
Kim McCoy	Ocean Sensors Encinitas, CA	619-943-7119

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6.	CDR Douglas L. McKinney 9 Glenn Avenue Salinas, CA 93907	2
7.	Director Naval Oceanography Division Naval Observatory 34th and Massachusetts Avenue NW Washington, DC 20390	1
8.	Commander Naval Oceanography Command NSTL Station Bay St. Louis, MS 39522	1
9.	Commanding Officer Naval Oceanographic Office NSTL Station Bay St. Louis, MS 39522	1
10.	Commanding Officer Fleet Numerical Oceanography Center Monterey, CA 93943	1
11.	Commanding Officer Naval Ocean Research and Development P.O. Box 3000 Bay St. Louis, MS 39522	1

12. Commanding Officer 1
Naval Environmental Prediction
Research Facility
Monterey, CA 93940

13. Chairman, Oceanography Department 1
U.S. Naval Academy
Annapolis, MD 21402

14. Chief of Naval Research 1
800 N. Quincy Street
Arlington, VA 22217

15. Office of Naval Research (Code 420) 1
Naval Ocean Research and Development
Activity
800 N. Quincy Street
Arlington, VA 22217

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School of Oceanography
Oregan State University
Corvallis, OR 97331

21. Commander 1
Oceanographic Systems Pacific
Box 1390
Pearl Harbor, HI 96860

22. Office of Naval Research 1
Code 1122PO
800 N. Annex St.
Arlington, VA 22217
Attn: Dr. Mel Briscoe

23. Dr. David Brooks 1
Texas A&M
College of Geophysics
College Station, TX 77843-3146

24. Dr. Dan Frye 1
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

Thesis
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c.1 Near real time VHF telemetry of near shore oceanographic data.

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